THE ROTHAMSTED MONOGRAPHS ON AGRICULTURAL SCIENCE

EDITED BY

SIR E. JOHN RUSSELL, D.Sc., F.R.S.

FIFTY YEARS OF FIELD EXPERIMENTS

AT THE

WOBURN EXPERIMENTAL STATION

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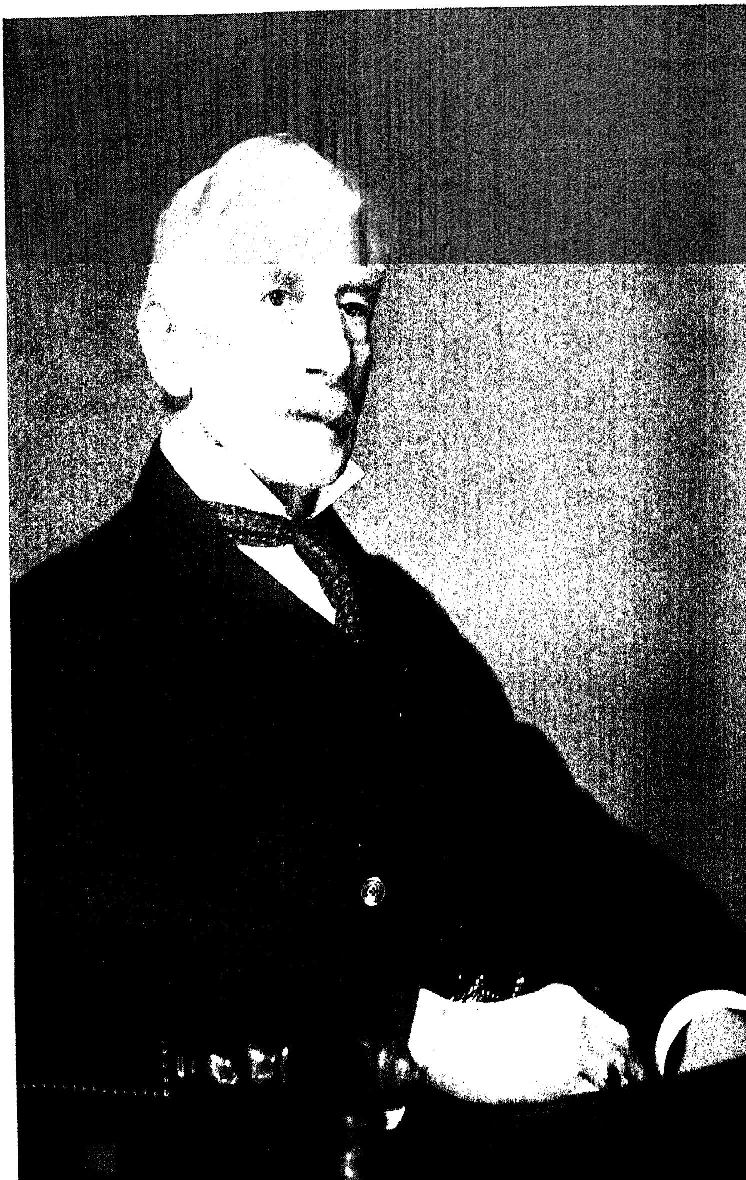

Dr. J. Augustus Voelcker

who took charge of the Woburn experiments from 1884 to the present time.

FIFTY YEARS OF FIELD EXPERIMENTS

AT THE

WOBURN EXPERIMENTAL STATION

BY

SIR E. JOHN RUSSELL, D.SC., F.R.S.

AND

DR. J. A. VOELCKER, C.I.E., M.A.

WITH A STATISTICAL REPORT BY

W. G. COCHRAN, B.A.

(ROTHAMSTED STATISTICAL DEPARTMENT)

WITH ILLUSTRATIONS

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INTRODUCTION.

The Woburn Experimental Station was founded in 1876 by the Duke of Bedford and the Royal Agricultural Society for the purpose of carrying out certain experiments for which provision could not otherwise have been made. At that time the Rothamsted Experimental Station, already more than 30 years old, was the only one in existence in Great Britain, and it was the private property of Sir John Lawes, who had founded it in 1843. The new station had the entire sympathy and support both of Lawes and of Gilbert, and they took an active part for many years in advising in regard to the programme and results.

One of the chief problems to be investigated was to discover the extent to which the productiveness of the soil was influenced by the feeding of concentrated foods, such as cake and corn, to the live-stock on the farm. These rich foods obviously enriched the manure which in turn should raise the productiveness of the land. By the Agricultural Holdings Act of 1875, a tenant leaving his farm was entitled to compensation for the value of the improvement he

had effected in the holding during his tenancy, and among these improvements was the enhancing of fertility due to the feeding of cake and corn.

It is difficult for us now to realise what a marked change this meant in the relations of landlord and tenant in England. For generations farmers quitting their holdings, either of their own free will or at the command of the landlord, had no legal claim to compensation for any improvement they had effected in the soil. It was held "that the landlord could do what he liked with his own," and if he chose to dispossess a tenant he could do so: it had been to the tenant's own advantage to improve the soil, but as this still remained the landlord's property he could have no grievance if he had to give up without compensation at the end of his tenancy.

In practice the hardship was usually mitigated by various "Customs," such as the "Norfolk Custom," the "Lincolnshire Custom," and others, as the result of which an outgoing tenant was awarded some compensation based on the amount of his feeding-stuffs bill for the last years of his tenancy.[1] But this was an act of grace and of custom, and not a legal right.

With the changing economic and political conditions of the nineteenth century these old "Customs" were doomed. The first definite blow came in 1870 when Mr. Gladstone's Irish Land Act awarded to an

[1] An account of some of these "Customs" is given by J. B. Lawes in *J. Roy. Agr. Soc.*, 1885, vol. 21 (2nd series), p. 590: Rothamsted Memoirs, vol. 6, No. 7.

outgoing tenant compensation for "Tillages, manures, and other like farming works, the benefit of which is unexhausted at the time of the tenant quitting his holding." The Act, as Lawes shrewdly observed, was very explicit in all that related to the legal machinery for trying the claims, but it said nothing about what constitutes unexhausted value or how that value is to be determined. Trouble soon arose, as might be expected. In 1873 an Englishman farming under the Duke of Leinster on quitting his holding put in a claim for £4900 compensation, but pressed only for £1170. He was offered £123 2s. in settlement. There resulted a lawsuit, in which Lawes gave evidence. "During the trial," says Lawes, "I had ample opportunity of observing how great were the difficulties with which both the judge and the opposing counsel had to contend." [1]

Lawes had already been thinking about this problem and had suggested basing the "custom" not on the price but on the composition of the feeding-stuffs, recognising, as the "custom" failed to do, that the manurial value depended on the nitrogen, potassium, and phosphate that found its way into the manure. He deducted from the weight of these elements contained in the food the quantities which he had shown to be retained in the animal's body and so obtained a value for the quantities present in the

[1] Lawes published an account of this in a pamphlet, *Unexhausted Tillages and Manures, with special reference to the Landlord and Tenant (Ireland) Act*, 1870: Roth. Memoirs, vol. 3, No. 14.

manure. On this basis he drew up his first Table, which he says was published in 1860:[1] he elaborated it in a paper read before the Farmers' Club in 1870,[2] and still more in later papers in the *Journal of the Royal Agricultural Society.*[3]

This afforded a definite scientific basis for the valuation and obviated the need for the prolonged and rather futile discussions that had occurred during the trial in question.

Lawes' Table was not at first universally accepted: it was criticised on the score that many of his values were too high.

The question could obviously not be settled by mere discussion: it was decided to carry out the necessary field experiments, and through the generosity of the Duke of Bedford and the public-spirited action of the Royal Agricultural Society the Woburn experiments were begun.

The problem proved more difficult than was expected, and even after 60 years of work it remains uncertain whether any rigid basis of compensation can be drawn up. In practice valuers exercise con-

[1] We have failed to find this publication. In 1859 Lawes and Gilbert published their classical memoir on the "Composition of Oxen, Sheep, and Pigs and their Increase whilst Fattening" (*Phil. Trans.*, 1859, vol. 149, p. 493: also in *J. Roy. Agr. Soc.*, 1860, vol. 21, p. 433 (Roth. Memoirs, vol. 2, No. 2), where the data are given but no Tables. See also J. B. Lawes, *J. Roy. Agr. Soc.*, 1862, vol. 23, p. 45, and Roth. Memoirs, vol. 1, No. 15.

[2] "Exhaustion of the Soil in Relation to Landlords' Covenants and the Valuation of Unexhausted Improvements," Farmers' Club, April 4, 1870: Roth. Memoirs, vol. 3, No. 9.

[3] *J. Roy. Agr. Soc.*, 1875, vol. 2 (2nd series), p. 1; 1885, vol. 21 (2nd series), p. 590: Roth. Memoirs, vol. 6, No. 7.

siderable discretion, and judge of the fertility of the soil from the crops, rather than from what the farmer has put into the land, although account is taken of this as of all other relevant considerations.

At the same time a series of experiments on the continuous growth of wheat and barley was begun, these experiments being on similar lines to those at Rothamsted, and, like them, designed to test the ideas on soil fertility that were current when the Rothamsted experiments started.

The old idea had been that soil organic matter constituted the food of plants and therefore the basis of soil fertility. This had been controverted by Liebig who maintained that the mineral constituents of plants, and not the organic matter, formed their proper nutrients, and therefore were the most important factors in soil fertility. Lawes and Gilbert did not dispute the necessity for adequate supplies of mineral constituents: indeed, Lawes showed how to use them in practice; but they emphasised the need for adding nitrogenous compounds also. Liebig disputed this, as well as other conclusions of Lawes and Gilbert in regard to his "mineral theory," as it was then called, and the ensuing controversy remained one of the great interests in Gilbert's life: it formed part of the plan of the Woburn field experiments.

The results obtained on the light soil at Woburn fully confirmed those of the heavier soil at Rothamsted: they constitute an important part of the classic

material relating to this problem. The controversy is now long ended and has passed into the domain of history.

The wheat and barley experiments, however, still retain their interest. Valuable information has been obtained about the effects of soil and climatic conditions on the effects of fertilizers and manures on plant growth: this is set out in the subsequent chapters.

A third important series of experiments had to do with green-manuring, especially to test the value of tares and mustard as preparation for wheat. In spite, however, of the addition of substantial quantities of green-manure, no beneficial effect was produced on the crop.

The conduct of the experiments was in the hands of Dr. Augustus Voelcker from 1876 to his death in 1884. It was then taken over by his son, Dr. J. A. Voelcker. In October, 1921, the Royal Agricultural Society gave up the farm, but Dr. Voelcker continued it himself till October, 1926, when the Rothamsted Committee took it over, and now includes it as a sub-station under the same Committee and management as the Rothamsted Station.

The design of the Woburn field experiments was almost the perfection of the old method of single plots systematically arranged. It is admirable for demonstration of ascertained facts. Unfortunately it takes no account of differences in the nature of the soil and the subsoil; it assumes that these are equal

over the whole area ; it assumes also that differences resulting from different treatment of the various parts of the area prior to the commencement of the experiments will not long continue. Both assumptions are now known to be false ; soil and subsoil are not uniform, and some of the crop results, if acceptable at all, show that comparatively small differences in treatment maintained only for a few years produce remarkably persistent effects. There is, therefore, an element of doubt about many of the conclusions that can be drawn from the figures because of the possibility that the results are really attributable to soil variations, and not to the direct treatment at all. A conclusion can, of course, be strengthened if supporting evidence can be adducted, but it never loses its element of uncertainty.

This difficulty can probably never be entirely overcome, but in modern designs of field experiment it is obviated by repeating and randomising the plots in such a way that the significance of differences in yield can be estimated. The results are given along with their standard error, which is virtually a statement of the odds that a particular result is really due to the treatment and not to the soil irregularities. The usual convention is to accept odds of about 20 to 1 ; results not coming up to this standard may still be true but the figures do not prove it. Most of the important modern experiments are on these lines, so that the difficulties which have arisen in regard to the Woburn data will not cause so much trouble in future.

In spite of this difficulty, however, the Woburn experiments have been so well done that the results contain a great amount of valuable information, which it has been our purpose to extract.

In recent years methods have been devised in the Statistical Department at Rothamsted for studying data of the kind these experiments furnish, and these methods are capable of extracting much more information than can be obtained by mere inspection of averages, such as has hitherto been usual among agricultural experimenters.

Through the support of the Research Fund of the Royal Agricultural Society, Miss A. M. Webster was appointed at Rothamsted in 1929 to apply, under Dr. R. A. Fisher's direction, the new statistical methods to the Woburn data. She did the laborious work of transcription, checking, and tabulation, and made the prolonged and tedious calculations which form the basis of the second and third parts of this volume. She gave up the work for good personal reasons, and was succeeded by Mr. W. G. Cochran who completed it and has described the results in several of the chapters of this book.

The very special nature of the subject has required correspondingly special treatment, and a little explanation of the design of the book is due to the reader.

Part I. is an account by Dr. Voelcker of the experiments. As the son of one of the distinguished founders of the Woburn farm, he has been directly responsible for them since 1885: no one else could

possibly have stated as authoritatively as he what has actually been done at Woburn. Unfortunately, limitations of space compelled me to omit experimental work of which the interest is now only historic: I did this with less hesitation because full accounts appear in the *Journal of the Royal Agricultural Society* for the years in question. For the same reasons no account is given of the pot experiments, carried out under the Hills bequest. For these omissions I must be held entirely responsible. Dr. Voelcker is, however, proposing to publish a complete account of the whole of the Woburn work in a separate volume.

In Part II. Mr. Cochran applies to the data the statistical methods of examination worked out at Rothamsted, first by Dr. Fisher and later by his successor, Mr. F. Yates. In fairness to the methods, however, it must be stated that the data are not suitable for really detailed examination: the methods are at their best for field experiments when the plots have been properly replicated and randomised. And, moreover, several changes in the plan of the experiments had been made. To the agricultural experimenter one of the outstanding lessons of the Woburn experiments is the necessity for keeping to the plan and not changing it during the course of the work.

In spite of these disadvantages, however, some valuable results have emerged. The general need for nitrogenous fertilizer whether the soil be light or heavy; the need for lime when sulphate of ammonia

is used frequently; the fact that green manuring is by no means a trustworthy practice but is liable to break down badly even on soils where it would be most expected to do well; the serious losses incurred in using farmyard manure and in folding cake on the land: these and many other results have been definitely established. Further, a number of problems are raised of considerable interest in agricultural science and practice, and although the data, for the reasons stated above, give no clear answer, they furnish indications which subsequent experimenters will be able to utilise and to develop. In the third part of the book, I have brought together these various results.

Dr. E. M. Crowther has contributed an important summary of chemical studies of soil samples taken from the plots at various times.

Finally, the Appendix contains the primary data calculated direct from the field records.

The decision to leave out the pot experiments unfortunately necessitated the omission of interesting work by Dr. H. H. Mann. This, however, is still continuing and the results appear in the appropriate journals. Special thanks are due to him for much help in the preparation of the book.

I wish also to thank Mr. T. W. Barnes and Mr. H. V. Garner for their assistance.

E. J. RUSSELL.

ROTHAMSTED EXPERIMENTAL STATION,
HARPENDEN.

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PART I.—FIELD RESULTS OF THE WOBURN EXPERIMENTAL STATION.

BY J. AUGUSTUS VOELCKER, M.A., B.SC., PH.D.

CHAPTER I.

HISTORICAL.

THE Woburn experiments were commenced in 1876. Their inception was the direct outcome of the passing of the Agricultural Holdings Act (1875), which made the giving of compensation to an outgoing tenant for the unexhausted value of purchased food a subject for arbitration.

Following on this J. B. Lawes had published, in the spring of 1875, in the *Journal of the Royal Agricultural Society of England* (vol. 2, 1875, pp. 1–38), a paper "On the Valuation of Unexhausted Manures," containing a Table giving the Estimated Money Values of the manure obtained by the consumption of 1 ton of each of the commoner farm foods. This Table was based on the chemical composition of the foods, but allowed for the deductions due to increase of live-weight of the animals producing the manure, already ascertained by Lawes and Gilbert, as also for the losses in the making and subsequent storing of the manure. The different foods were arranged in the Table in order of their content of nitrogen, phosphoric acid, and potash, and the current market values of these constituents, as purchasable in manures, were assigned to them.

Practical men raised the question—How far do the values set out in Lawes' Table really represent what actually occurs; does the outgoing tenant get his due, or is the landlord or incoming tenant overcharged?

At the Council Meeting of the Royal Agricultural Society of England on November 3, 1875, Mr. Charles Randell, of Evesham, urged the desirability of settling the matter by direct experiments on different soils and under different conditions. The Chemical Committee was asked to consider how this could best be done. Its members were Mr. William Wells (chairman), the Earl of Lichfield, Lord Vernon, Messrs. J. D. Dent, J. B. Lawes, Jacob Wilson, C. Randell, and W. H. Wakefield. On February 3 and 4, and February 28, 1876, they heard statements by Mr. Lawes and Dr. Augustus Voelcker on the scientific side, and by Mr. E. P. Squarey, Mr. Jacob Wilson, Mr. Thos. Huskinson, Mr. B. Bomford, Mr. C. Randell, Mr. Jas. Martin, and Major Dashwood on the practical side. There was a general readiness to accept Lawes' Table modified to meet differing conditions, and a desire for experiments to test its validity, but much divergence of views as to what experiments were needed: some considered that the feeding values as well as the manurial values of some of the foods consumed on the farm should be ascertained. The scientific witnesses pointed out that would be a very complex investigation and, unless done on a large scale with foods differing widely in composition, would reveal no difference in feeding value and give no definite conclusions.

Some witnesses, like Mr. Randell, considered that the experiments could be made by a farmer in his ordinary farm practice without special staff or supervision, but the majority, especially the scientific witnesses, emphatically maintained that they could be carried out only by skilled men under scientific direction. If the Royal Agricultural Society undertook them the results would command confidence.

This view was reported to the Council on April 5, 1876.

Dr. Augustus Voelcker

Director of the Woburn Experiment Station
from its inception in 1876 till his death in 1884.

Meantime the then Duke of Bedford (Hastings Russell) generously offered the use of land on his Estate at Woburn, and funds to pay the cost of the experiments, provided the Royal Agricultural Society would undertake their entire direction and management. This noble offer made the Committee's task comparatively easy, and they accordingly recommended its acceptance, and asked Mr. Lawes and Dr. A. Voelcker to draw up a scheme for the proposed experiments. It was recognised that these must continue for a number of years. The Committee suggested that Dr. Voelcker might also devise experiments that practical farmers could do in their own districts, though they attached little importance thereto.

The Council adopted the Committee's report on April 5, 1876. Subsequent events have justified the view of the scientific witnesses that the work would prove difficult. The enquiry was limited to the manurial problem and to two foods only, viz. cake (decorticated cotton cake) and corn (maize-meal), yet after 50 years of experiments no definite answer can be given. Lawes' Tables have, it is true, been generally adopted, with modifications introduced first by Lawes and Gilbert themselves, and later by Hall and J. A. Voelcker, yet there is no direct experimental evidence to support them.

The land, generously placed at the disposal of the Society by the Duke of Bedford, was known as Crawley Mill Farm. It originally consisted of 90 acres, of which 67 were arable and 23 were grass. The arable land is a light, sandy loam, on the Lower Greensand formation; the grass land is heavier, the sand being mingled with the Oxford clay: the change occurs just at the farm buildings. Warren Field on the heavier land was originally intended for the experiments, but its soil was soon found to be too variable. The Duke thereupon added to the farm Stackyard Field, one mile distant and nearer Woburn; this became, and has since remained, the real "experimental field" of the Station.

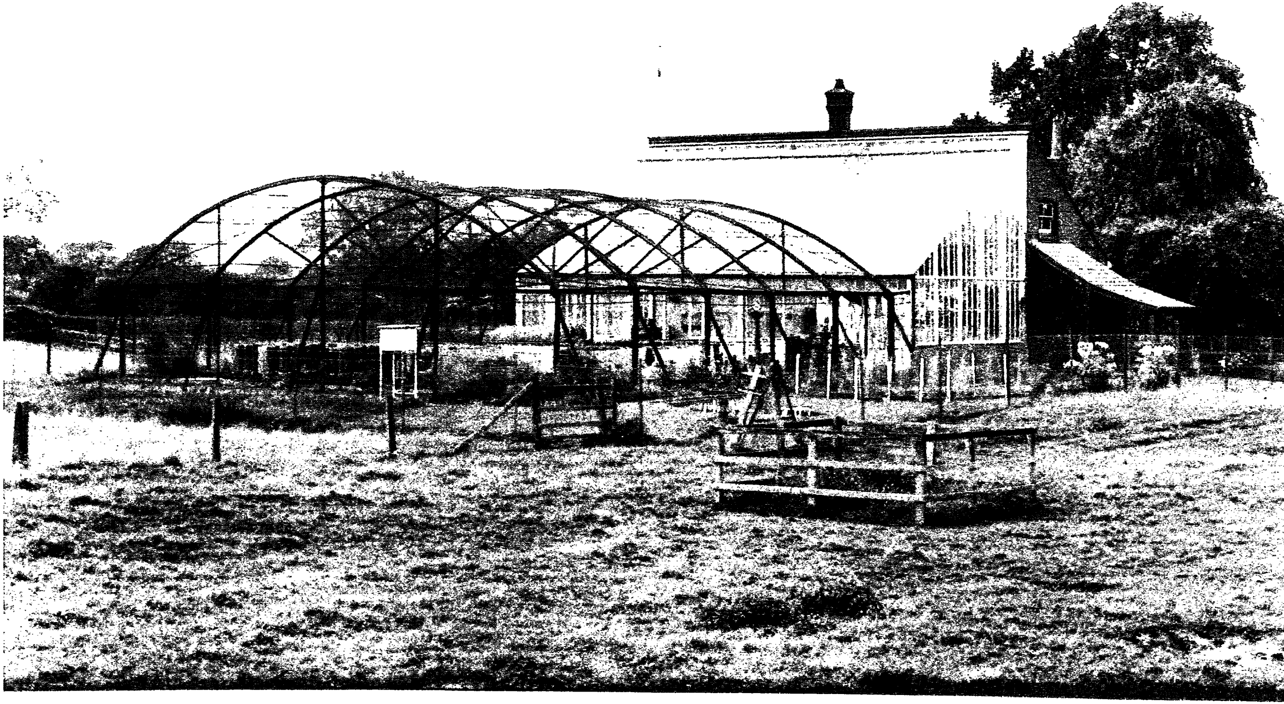
He also increased the resources of the Farm by adding to the existing buildings a set of eight special feeding boxes for cattle. The Farm thus reconstituted comprised 131 acres.

The Duke paid all the expenses and the Society provided the requisite labour, management, and direction. This arrangement continued throughout his life and that of his son (the 10th Duke), and until 1910 when the present (11th) Duke (Herbrand Russell) withdrew his support on the setting up of the Development Commission which thereupon made an annual grant of £500; this has been continued to the present time. Up to October, 1921, the Royal Agricultural Society met all further expenditure: then they decided to give up the work; for five years Dr. J. A. Voelcker himself undertook the responsibility for carrying on, till October, 1926, when the Lawes Agricultural Trust took over the Farm and now manages and finances it.

In 1897 the late Mr. E. H. Hills left the Society a legacy of £10,000 for the purpose of carrying out experiments on the influence of the less commonly occurring constituents of plants and soil. The income from this bequest enabled a Laboratory and Pot-culture Station to be built and provided for the necessary chemical work: in 1921, however, the Society handed over the income to the Cambridge School of Agriculture.

At the outset the Farm was managed by the Woburn Sub-Committee of the Chemical Committee of the R.A.S.E. The first Chairman was Lord Vernon (1878-80), the next Sir Archibald K. Macdonald, Bart. (1881), and then came Mr. William Wells, of Holme, Peterborough, who served from 1881 to 1889. For many years during this earlier period Mr. Reginald A. Warren was a member, and, being connected with the Bedford Estate, rendered valuable service in negotiations with the Duke.

Mr. Wells was followed as Chairman by Viscount Emlyn (afterwards Earl Cawdor), (1889-98), then by Mr. Stanyforth



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(1899–1901), Mr. (later Sir John) Bowen Bowen-Jones (1901–1914), and Mr. J. L. Luddington (1915–21).

Prominent members of the Sub-Committee at various times have been Sir John Lawes, Lord Vernon, Sir John Thorold, Messrs. J. Dent Dent, Charles Howard (Bedford), Herbert Little (March), Sir Archibald K. Macdonald, Albert Pell, Faunce de Laune, Martin J. Sutton, Joseph P. Terry, Howard P. Ryland, F. Reynard (Driffield), W. A. Prout, Christopher Middleton (Darlington), J. H. Howard, A. P. Turner, James Falconer and Fred. Smith (Woodbridge).

Sir John Lawes and Dr. Augustus Voelcker (then Consulting Chemist to the Society) drew up the plan of the experiments and undertook their scientific supervision. The first Report (1877) was issued jointly by them. Sir John Lawes in May, 1878, withdrew from active participation but retained his interest in the work. Dr. Voelcker died in December, 1884, and was succeeded in March, 1885, by his son, Dr. J. A. Voelcker, who retained the Directorship till the Farm was taken over by the Lawes Agricultural Trust in 1926, and who still gives his services as Honorary Local Director.

The resident Farm Manager has usually been a young man of promise, and several of them have subsequently had distinguished careers: the first was Mr. W. J. Malden, the well-known agricultural writer (1878–84); he was succeeded by Messrs. F. E. Frazer (1884–9), Arthur E. Elliott (1889–94), now agent to the Duke of Newcastle, C. H. B. Cane (1894–6), J. J. Forrester (1896–1901), killed in the Boer War (1901), W. H. Hogg (1901–12), who later joined the Ministry of Agriculture, and F. C. Atkinson (1913–21). Mr. Elliott's son is the present Agent of the Duke of Bedford.

Up to 1897 any analyses required in connection with the experiments were carried out in the Royal Agricultural Society's laboratory in London; this, however, owing to distance and delay, often proved somewhat unsatisfactory. After the Hills bequest had enabled a laboratory to be built

a resident chemist was appointed: the first was H. H. Mann (1897–1900), who later had a distinguished career in India, then followed Harry M. Freear, who died at his post in October, 1914: then came James Crabtree (1914–December, 1919), who became Superintendent of Experimental Sugar Farms in Demerara. He was followed by A. Blenkinsop (1919–26), now at the Seale-Hayne Agricultural College, Newton Abbot. In October, 1928, Dr. Mann returned to Woburn as Resident Assistant Director, generously giving his whole time and energy to the work without remuneration of any kind.

From the outset it was realised that the experiments formed the main purpose of the Farm: two extracts from the Minutes of the Sub-Committee had clearly shown this:

Dec. 1877.—"This scheme (for Woburn) recognises that the Experimental Field is of the first importance, and that the Crawley Farm is to be looked upon as an adjunct thereto. The Farm is to be managed with a view to supply such buildings, material, and labour as may be, from time to time, required for the proper conduct of the investigations now being carried out on the Experimental Field."

April 1878.—"The management of Crawley Farm should at all times be subservient to the operations required in the Experimental Field."

CHAPTER II.

THE RESIDUAL MANURIAL VALUES OF CAKE AND CORN FED TO ANIMALS IN YARDS OR ON THE LAND. STACK-YARD FIELD EXPERIMENTS.

It was decided to start with the comparison of decorticated cotton cake and maize-meal. At that time (1876) figures for composition of these two foods and for the compensation payable according to Lawes' Tables were :—

	Nitrogen, per cent.	Money Value of the Manure from One Ton Fed.
		£ s.
Decorticated cotton cake	6·6	6 10
Maize-meal . . .	1·7	1 11

These two foods, differing widely in nitrogen content and manure value, were used in two ways for making manure: they were fed to bullocks making farmyard manure under cover, and also to sheep folded on the seeds. The manurial effects on the succeeding crop, roots after the manure and wheat after the folding, were compared with those given by artificial fertilizers supplying the same amounts of nitrogen and phosphate as were calculated to come from the foods.

First Period, 1877-85.—Sixteen acres of Stackyard Field were set out in four equal-sized blocks, each to be under the four-course rotation—Roots, Barley, Seeds,[1] Wheat, and

[1] The "seeds" crop from 1877 to 1880 was red clover and rye grass; from 1881 to 1884 Dutch white clover alone.

so arranged that one of each of the four crops should be grown each year. Each block was further divided into four plots of 1 acre each. The cropping was as follows :—

	Rotation I.	Rotation II.	Rotation III.	Rotation IV.
1877	Seeds	Roots	Barley	Barley
1878	Wheat	Barley	Seeds	Roots
1879	Roots	Seeds	Wheat	Barley
1880	Barley	Wheat	Roots	Seeds
1881			Barley	Wheat
	4 | 3 | 2 | 1	4 | 3 | 2 | 1	4 | 3 | 2 | 1	4 | 3 | 2 | 1
	4 acres.	4 acres.	4 acres.	4 acres.

Seeds.[1]—All four of the seeds plots were fed off by sheep. On Plot 1 the sheep received in addition 672 lb.[1] per acre decorticated cake ; on Plot 2, 728 lb. per acre maize-meal. On Plots 3 and 4, no additional food was given.

Wheat.—Plots 1 and 2 received no manure. Plots 3 and 4 received artificial manures equivalent to manure from 728 lb. maize-meal and 672 lb. decorticated cotton cake respectively ; the quantities are given below.

The yield of wheat thus afforded a measure of the fertilizer values of the cake and corn residues in terms of the artificials given.

The *root crop.*—All plots received dung made in the special boxes by cattle receiving roots and chaff,[2] and, in addition, for Plot 1, 1000 lb. decorticated cotton cake ; Plot 2, 1000 lb. maize-meal ; Plots 3 and 4, no additional food.

Plots 1 and 2 had no artificials, but Plots 3 and 4 received artificial manures equivalent to the maize-meal manure

[1] In 1877 728 lb. decorticated cake were fed, but in 1878 only 672 lb. were freely taken by the sheep. This quantity was adhered to until the end of the experiment.

[2] 5000 lb. mangolds ; 1250 lb. wheat ; 1300–3230 lb. straw as litter.

and to part of the decorticated cotton cake manure respectively :—[1]

	Plot 3. Equivalent to Cotton Cake.		Plot 4. Equivalent to Maize-meal.	
	1000 lb. [Roots].	672 lb. [Wheat].	1000 lb. [Roots].	728 lb. [Wheat].
Nitrate of soda . . .	372	250	80	58
Superphosphate . .	100	67	17	12
Sulphate of potash .	63	42	7	5
Sulphate of magnesia .	65	43	11	8
N	58	39	12	9
P_2O_5	33	22	5	4
K_2O	31	21	4	3

372 lb. per acre of nitrate of soda was deemed too high for one dressing, hence two-thirds of this amount was given to the roots and one-third to the succeeding barley. All the roots were fed on the land and barley was then grown.

Barley.—Plot 3 received 124 lb. per acre nitrate of soda (19 lb. nitrogen), the other plots received nothing.

Seeds.—No manure.

The total nitrogen furnished from the cake and corn in the sheep and cattle manure was estimated at the time as follows :—

	Lb. per Acre.
From decorticated cotton cake . . .	96
„ maize-meal	21

[1] The equivalent amounts of artificial manure were calculated as done by Lawes in constructing his Table of the estimated manurial value of feeding-stuffs. A loss of 10 per cent of the nitrogen of cotton cake, and 15 per cent of the nitrogen of maize-meal was assumed. This estimate of loss is certainly too low where manure was made and then carried on to the field. In 1899, 1900, and 1901 Dr. J. A. Voelcker found by actual analysis that the loss was about 32 per cent, so that the quantities of artificial manure given to the root crop were too large. From Dr. Voelcker's work we can get a rough estimate of the amounts of nitrogen which went on to the land in each application of the cake and meal ; these are :—

		N. lb.	
Cotton cake	1000 lb. (converted into F.Y.M.)	43	82
	672 lb. (fed on to the land)	39	
Maize-meal	1000 lb. (converted into F.Y.M.)	10	19
	728 lb. (fed on to the land)	9	

As shown on p. 9 these values are too high, insufficient allowance having been made for losses in making the dung, but even so the differences amounts to some 63 lb. per acre of nitrogen, the equivalent of about 3¾ cwt. of nitrate of soda in favour of the cake dung.

The results for the first series of crops (1877-85) are given in Table I.

TABLE I.—AVERAGE ANNUAL PRODUCE PER ACRE DURING THE FIRST AND SECOND ROTATIONS, 1877-85.

	Roots, 1877-84. Mangolds, 1877-81.	Roots, 1877-84. Swedes, 1882-84.	Barley, 1878-85. Head Corn	Seeds, 1877-84. Increase of Live weight of Sheep Fed on Seeds	Wheat, 1879-85.
	Tons.	Tons.	Bushels.	Lb.	Bushels.
Dec. cotton cake dung .	12·05	17·3	46·3	36·2	40·2
Maize-meal dung .	11·8	17·0	45·8	35·6	41·8
Artificial equivalent of dec. cotton cake dung	10·55	10·85	48·7	24·8	40·4
Artificial equivalent of maize-meal dung .	13·0	18·2	43·3	25·0	41·6

The cake dung applied to the roots gave practically no greater yield than the maize dung in spite of its additional nitrogen, nor was there any difference in the following barley. The artificial equivalent of the maize dung was somewhat superior to the dung itself for the roots, the cake equivalent being better than the maize equivalent.

The sheep had gained more weight as the result of receiving cake or corn, but the following wheat crop showed no difference in manurial value between these two foods.

Second Period, 1885-96.—Dr. Voelcker died in 1884 and left no record of his views as to the reason why the experiment had failed to bring out the expected differences between cake and corn. In taking over the work, Dr. J. A. Voelcker noticed that the yields both of barley and of wheat were

higher than on the closely adjoining continuous barley and wheat series for the same years, even on the best plots :—

	Barley, bushels.	Wheat, bushels.
Plot 6 (nitrate of soda and minerals) . .	40	32·4
Plot 11b (farmyard manure)	40	26·7

He supposed therefore that even the poorer manuring (with maize-meal) had given the maximum crops of wheat and barley which the land was capable of producing, and hence the benefit of the richer (more nitrogenous) manuring with cake could not be brought out. The plan of the experiments was therefore modified, and arranged as follows :—

Rotation I.				Rotation II.				Rotation III.				Rotation IV.			
Area, 16 acres															
8	7	6	5	8	7	6	5	8	7	6	5	8	7	6	5
C	lov	er			Man	gol	ds		Ba	rle	y		Whe	at	
This half not manured since 1885, and crops carted off.															
C	lov	er			Sw	ede	s		Ba	rle	y		Whe	at	
4	3	2	1	4	3	2	1	4	3	2	1	4	3	2	1
Manured once in the rotation by roots fed on with cotton cake or maize-meal respectively.															
Hedge and Road.															

On the upper portion nearest the road the manuring with cake and corn was continued on the same plots, but on a much reduced scale, no dung being applied to the roots and no cake or corn being fed with the "seeds." The roots (swedes) received only 3 cwt. superphosphate, and after being weighed, 3 to 5 tons per acre of them [1] were fed off on each of the four

[1] An equal weight of roots was carted from each plot, and the quantity left was therefore related to the difference in yield on the plots : e.g. if one plot had yielded 10 tons and the other 12, 7 tons would be carted off from each, leaving 3 and 5 tons to be fed to the sheep.

plots by sheep receiving, on Plot 1, 400 lb. per acre decorticated cotton cake, on Plot 2, 400 lb. per acre maize-meal, and on Plots 3 and 4, no additional food beyond a little chaff, but the respective equivalents [1] in artificial manures of the decorticated cotton cake dung and of the maize-meal dung were applied to the barley that followed.

On the lower portion the crops were grown entirely without manure and were all carried off after being weighed; there was no folding.

It was hoped in this way to exhaust some of the extra fertility conferred by the liberal treatment of the previous 8 years, and so enable the differences between cake and corn to be brought out.

The new series was accordingly:—

	Rotation I.	Rotation II.	Rotation III.	Rotation IV.
1885	Peas and tares.[2]	Swedes and mangolds.[3]	Barley.	Wheat.
1886	Wheat.	Barley.	Seeds.	Roots.
1887	Roots.	Seeds.	Wheat.	Barley.

This treatment continued throughout the next 12 years (1885–96) with occasional breaks owing to the failure of some one or other crop. Thus, the swede crop partly failed in 1886, 1890, and 1892; in 1887 mangolds failed on the lower half and were replaced by swedes; in 1888 the clover was weighed green and not as hay; and in 1896 peas took the place of clover on the upper portion of the field (Plots 1, 2, 3, 4).

The yields for the individual years 1885–97, embracing

[1] Determined by analysis of each year's samples of cake and meal; usually about 150 lb. per acre nitrate of soda on Plot 3, and 32 lb. per acre on Plot 4, with corresponding changes in the minerals.

[2] Peas on upper part, tares on lower, but both failed.

[3] Swedes on upper part, mangolds on lower part.

three more rotations, are given in Table 2.[1] The results were as follows:—

TABLE 2.—ROTATION EXPERIMENTS: STACKYARD FIELD, 2ND SERIES 1885–96.

AVERAGE ANNUAL PRODUCE PER ACRE DURING THE THIRD, FOURTH, AND FIFTH ROTATION, 1885–96.

Plot.	Manures per Acre.	Roots, 1885–96. Swedes.	Barley, 1886–96. Head Corn.	Clover,[2] 1889–95. Hay.	Wheat, 1886–96. Head Corn.
		Tons.	Bushels.	Tons.	Bushels.
1	3 cwt. superphosphate to swedes. 400 lb. decorticated cotton cake to sheep consuming them	10·45	37·7	2·35	33·9
2	3 cwt. superphosphate to swedes. 400 lb. maize-meal to sheep consuming them . .	10·5	34·7	2·45	32·4
3	3 cwt. superphosphate to swedes. No cake or meal to sheep consuming them. Artificial equivalent of the cotton cake dung applied to succeeding barley .	10·5	40·6	2·55	33·0
4	3 cwt. superphosphate to swedes. No cake or meal to sheep consuming them. Artificial equivalent of the maize-meal dung applied to succeeding barley .	10·0	34·5	2·5	32·1
		Mangolds.			
5[3]	No manure . . .	11·2	25·5	2·05	31·1
6	No manure . . .	11·6	25·7	2·3	31·0
7	No manure . . .	11·95	27·2	2·35	32·1
8	No manure . . .	10·95	25·8	2·25	31·4

[1] *J. Roy. Agr. Soc.* (3rd series), vol. 9, 1898, pp. 700–19, with a summary of results on page 721. The results for a few individual years are omitted, e.g. 1887, when mangolds failed on the lower portion and swedes were grown instead; 1888, when, owing to wet weather at the time, the clover had to be weighed green; 1886, 1887, and 1896, when peas and tares took the place of "seeds."

[2] From 1885 to 1887 tares and peas were grown. From 1888 to 1897 red clover, except in 1896 when the red clover sown in 1895 failed and peas were grown. No signs of "clover sickness" were observed.

[3] Prior to 1885 Plot 5 had formed part of 1, Plot 6 of 2, Plot 7 of 3, and Plot 8 of 4.

1. *Roots.*—Neither swedes nor mangolds showed any differences in yield.

2. *Barley.*—This was the only crop for which decorticated cotton cake showed an advantage over maize-meal. The difference was 3 bushels per acre compared with 6 bushels per acre more when the equivalent artificial manures were used.

The unmanured plots (5, 6, 7, 8) yielded 12 bushels per acre less than the manured plots but with no differences resulting from their previous history.

3. *Seeds (Clover).*—There were no differences in yield.

4. *Wheat.*—Again there were no differences in yield, and even the unmanured plots gave only 1½ bushels less than the manured.

The conclusions to be drawn are :—

(1) The barley immediately following the feeding off is the only crop to show a difference between decorticated cotton cake and maize-meal ; the subsequent seeds (clover), wheat, and roots show no difference.

(2) The artificial equivalent of the dung has usually done better for the barley than the cake or corn fed direct on the land. This suggests that the better results might be obtained by the supply of readily-available nitrogen in the form of nitrate of soda, a point of some importance which was followed up later in the enquiry.

The withholding of manure on the lower portion appreciably lowered the barley crops but had no effect on the others. This suggests that the clover crops supplied the succeeding wheat and roots with all the nitrogen they required so that they were not further benefited by nitrogen previously applied in the form of dung or artificials.

The average produce of wheat on unmanured plots (5 to 8) was still 31·4 bushels per acre in spite of the absence of manure during the 12 years 1885–96 : this compares with 30·1 bushels on Plot 6 (mineral manures with nitrate of soda) in the continuous wheat series over the same period.

It was therefore concluded that the land was still too rich, and so it was determined, after consultation with Lawes and Gilbert, to impoverish it by growing barley crops continuously and without manure for several years in the hope of bringing out the differences between the decorticated cotton cake and the maize-meal.

Third Period.—Barley grown without manure.

TABLE 3.—YIELDS OF BARLEY GROWN WITHOUT MANURE, AVERAGE 1898–1902.

Previous Treatment, 1886–97.		Bushels per Acre.	Previous Treatment, 1886–97.		Bushels per Acre.
Plot 1.	Cotton cake feeding	20·5	Plot 5.[1]	No manure	19·6
,, 2.	Maize-meal feeding	21·3	6.	No manure	21·3
,, 3.	Artificial equivalent of cotton cake dung . .	21·4	7.	No manure	19·1
,, 4.	Artificial equivalent of maize-meal dung . .	20·9	8.	No manure	19·5

The differences in yield were insignificant, whether manuring had continued to 1897 or stopped in 1885. No residual benefit could be detected from the cotton cake as against maize-meal.

The average yields having fallen from 36·9 bushels in the period 1886–96 to 21 bushels per acre, while the average yields of Plot 6 (minerals and nitrate of soda) in the continuous barley series for these years (1898–1902) had been 38·8 bushels per acre, it was assumed that a considerable amount of the accumulated fertility had been removed, and that the land was now fairly equalised. The original scheme was therefore re-started with certain modifications. A delay was necessary, because by 1902 the land had become overrun with weeds, and mangolds were grown in 1903 to clean the land. Owing to a very wet season that year, however, the land was little cleaner at the end than at the beginning, and it was decided to sow another cleaning crop in 1904.

[1] Prior to 1885 Plot 5 had formed part of 1, Plot 6 of 2, Plot 7 of 3, and Plot 8 of 4.

Kohl-rabi was grown on Plots 1 to 4 and mustard on Plots 5 to 8.

Fourth Period, 1904–11.—The changes were:

(1) Clover was replaced by a green crop, usually mustard weighed green.

(2) On Plots 1 to 4 the roots were made up to 12 tons per acre and then fed off to sheep receiving also clover hay and straw-chaff, and, on Plots 1 and 2, 920 lb. per acre of decorticated cotton cake and 920 lb. per acre of maize-meal respectively. The artificial equivalents of the cake and corn were, however, no longer given on Plots 3 and 4.

(3) On Plots 5 to 8 the root crop received manure made by bullocks fed on roots, hay and straw-chaff, etc., and, in addition, for Plot 5 decorticated cotton cake, and for Plot 6 maize-meal. For Plots 7 and 8 no additional food was given. The roots were made up to 12 tons per acre and then fed on the plots but without addition of cake or meal.

The experiment also tested cake (or corn) feeding of roots on the land against cake (or corn) manuring of the root crop direct, but as the years are different no effective comparisons can be made.

The quantities of cake and of corn fed to the sheep amounted to ½ lb. per head per day, which is quite a usual ration in practice. The amounts of ammonia supplied were (*a*) from the cotton cake 64·4 lb., (*b*) from the maize-meal 13·8 lb., a difference equivalent of an application of 2¼ cwt. of nitrate of soda per acre—which should be more than ample to discriminate between decorticated cotton cake and maize-meal, if the difference depended upon the nitrogen.

The bullocks making the dung for Plots 5 to 8 (on the lower half) were given 10 cwt. of cake or corn, i.e. about 25 per cent more than was fed to the sheep on Plots 1 to 4. The dressing of dung was about 4 tons to the acre. The cake fed to the bullocks supplied 78 lb. ammonia, and the meal 16·8 lb., a difference equivalent to nearly 3 cwt. per acre of nitrate of soda.

The results are given in Table 4.

TABLE 4. 1904–11, AVERAGE RESULTS PER ACRE.

	Roots, Tons per Acre.		Barley, Bushels per Acre.		Mustard, Green, Tons per Acre.		Wheat, Bushels per Acre.	
	No Manure, but previous Root Crop Fed to Sheep receiving— Plots 1–4. 1905–10.	Farmyard Manure. Plots 5–8.	After Sheep Fed on Preceding Root Crop. Plots 1–4. 1905–10.	Farmyard Manure to preceding Root Crop. Plots 5–8. 1905–10.	No Manure, after Sheep Fed on Root Crop. Plots 1–4. 1905–10.	Farmyard Manure to Root Crop. Plots 5–8. 1905–10.	No Manure, after Sheep Fed on Root Crop. Plots 1–4. 1906–11.	Farmyard Manure to Root Crop. Plots 5–8. 1906–11.
Cake . .	9·55	13·4	47·0	37·7	4·25	4·35	19·0	12·1
Corn . .	10·2	13·75	41·2	40·5	3·08	4·75	19·7	14·4
Neither cake nor corn .	11·1	14·4	40·6	37·3	4·0	4·1	19·9	12·7
Neither .	10·0	13·55	40·6	36·2	3·6	3·5	19·8	11·0

Notes to Table.—Note that only the barley had been manured on Plots 1 to 4 and only the roots on Plots 5 to 8.

On all plots 12 tons of roots per acre were fed off by sheep before the barley was sown.

From these results emerge as before; the only crop materially benefiting from the manurial treatment has been the barley following sheep fed on cake. In 1885–96, when clover was grown, the difference in yield had been 3 bushels per acre, now with mustard it is 6 bushels per acre. But no other crop in the rotation showed the slightest benefit from the cake, and none, not even the barley, benefited from the feeding of maize-meal.

The barley yield was considerably higher than in 1885–96, but the wheat yield was 12–14 bushels per acre less, showing the inferiority of mustard to clover as a preparation for wheat. The roots benefited from the farmyard manure, but there was no difference between the various lots of farmyard manure; neither cake nor corn feeding had any

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visible effect.[1] There was no sign of any residual effect. This may be associated with the mechanical factor that dung tends to make this light land too "open" and insufficiently consolidated.

In the continuous wheat and barley experiments over the period 1904–11 the yield of Plot 6 (minerals and nitrate of soda) was

(*a*) Wheat . . . . 19·9 bushels per acre
(*b*) Barley . . . . 27·5 ,, ,,

The absence of the "golden hoof" may in part account for the lower produce of barley grown continuously.

Fifth Period, 1911–17. In 1911 the plan was simplified. The area was reduced to one-half its former size, and the experiment confined to the 8 acres of Rotations III. and IV., henceforward called C. and D. respectively. The distinction of upper and lower halves was dropped, and the four plots in each rotation were reduced to two, each 2 acres in extent; corn was fed by sheep with the root crop on Plot 1 (the former 3, 4, 7, and 8), and cake on Plot 2 (the former 1, 2, 5, and 6).

The new plan was :—

Block C. (4 acres)		Block D. (4 acres)	
Corn	Cake	Corn	Cake

Rotation crops were grown as before, with green crops in place of clover. The cake fed per acre was 4 cwt. of linseed

[1] Note, however, the smallness of the dressing, and see p. 205 (E. J. R.).

cake and 4 cwt. undecorticated cotton cake, and the corn was 4 cwt. per acre of oats (crushed) and 4 cwt. barley (gritled). On each plot 2 cwt. per acre mixed clover-hay and oat-straw chaff was given. The cake supplied 45 lb. and the corn 18 lb. of ammonia per acre—a difference equivalent to $1\frac{1}{4}$ cwt. per acre of nitrate of soda.

Series C. (4 *acres*).—The swede crop of 1910 (on the former Rotation III.) had varied from $10\frac{1}{2}$ to 14 tons per acre. This was made up to a uniform amount of 12 tons per acre and fed off by sheep with corn on Plot 1 and cake on Plot 2.

In 1911 barley was grown, in 1912 red trifolium (weighed as hay), in 1913 wheat.

The swedes of 1914 received 3 cwt. of superphosphate and 1 cwt. of sulphate of potash per acre at the time of sowing. In 1916 rape was the green crop and was fed on the land, wheat following in 1917.

Series D. (4 *acres*).—The swedes following the wheat of 1911 were manured with 12 tons per acre of farmyard manure, 3 cwt. of superphosphate and 1 cwt. of sulphate of potash per acre at sowing; and 1 cwt. per acre of sulphate of ammonia later on as top-dressing. In 1912 12 tons per acre of the swede crop were fed on each half by sheep, those on Plot 1 receiving corn and those on Plot 2 cake, as in Series C.

In 1913 barley was grown; in 1914 mustard, fed off by sheep without cake or corn; in 1915 wheat; in 1916 swedes fed with cake and corn; and in 1917 barley. Thus C. and D. were no longer comparable because the crops were taken in different years.

The results for this period (1911–17), are given in Table 5.

These results were unsatisfactory and often contradictory, but they show no superiority of cake to corn for feeding on the land. The larger yields of swedes and barley in D. as compared with C. are probably due to the farmyard manure and artificials given to the swede crop of 1912.

TABLE 5.—YIELDS FOR PERIOD 1911–17.

	Series C.				Series D.			
	Swedes.	Barley.	Green Crop.	Wheat.	Swedes.	Barley.	Green Crop.	Wheat.
	Tons.	Bushels.	Tons.	Bushels.	Tons.	Bushels.	Tons.	Bushels.
1. Cake-fed plot .	6·9	24·2	1·8	19·5	13·6	32·1	Fed.	17·6
2. Corn-fed plot .	7·0	27·7	1·95	21·8	11·2	34·5	..	15·9

Sixth Period, 1918–26.—The last experiment having failed to yield any satisfactory result, yet another change was decided upon, this being to revert to the original plan of including clover in the rotation. The arrangement and division of plots remained as before, but the cake and corn mixtures were reduced to quantities supplying only 18 and 7·25 lb. nitrogen respectively, a difference equivalent to about 70 lb. of nitrate of soda per acre only.

Series C.—In 1918 swedes (following wheat) were fed (1.2 tons per acre) on the land to sheep, Plot 1 having cake and Plot 2 corn as before. Barley was grown in 1919 and red clover sown in it, wheat following as the 1921 crop.

Series D.—Barley was grown again in 1918, following the barley of 1917; red clover sown in it was the crop of 1919; wheat followed in 1920.

Still no success was attained, and in 1922 it was decided to widen the margin between the nitrogen supplied in the cake and the corn; decorticated cotton meal was accordingly added to the mixture of linseed and undecorticated cotton cake on Plot 1—now giving 67 lb. nitrogen per acre; while on Plot 2, barley and oats were used in quantity giving 29·25 lb. nitrogen per acre. The difference in nitrogen between the two sets thus amounted to 37·75 lb., the equivalent roughly of 2 cwt. per acre of nitrate of soda. This increased amount, it was thought, would surely "tell" in the respective crops grown.

The results obtained in Series C.,[1] however, in no way tended to bring out the desired difference, as is shown in Table 6.

TABLE 6.—YIELDS AFTER SWEDES FED WITH CAKE OR CORN, 1919–25.

Plot.	Cake giving Nitrogen 18 lb. per acre; Corn 7·25 lb. per acre.				Cake giving Nitrogen 67 lb. per acre; Corn 29·25 lb. per acre.		
	1919. Barley (after Roots Fed with Cake or Corn).		1920. Clover-Hay.	1921. Wheat.	1923. Barley (after Roots Fed with Cake or Corn).	1924. Clover-Hay.	1925. Wheat.
		Bushels.	Tons.	Bushels.	Bushels.	Tons.	Bushels.
1.	Cake-fed	18·2	2·8	31·2	16·2	1·85	25·8
2.	Corn-fed	17·4	2·8	37·4	14·2	1·9	24·6

In both rotations a slightly higher yield of barley was obtained from the cake feeding—in the earlier periods—but nothing commensurate with the difference which an equivalent quantity of nitrate of soda over acre might be expected to produce.

In the clover-hay crop there was no difference, and from the wheat crops no conclusion could be drawn.

When the wheat and barley crops were averaged for the whole of the last set of periods 1911–31 the yields after cake and corn feeding are shown in Table 7 to be practically the same.

TABLE 7. MEAN YIELDS, 1911–33. CWT. PER ACRE.

	Series C.		Series D.	
	Corn.	Cake.	Corn.	Cake.
Barley (6 years), Grain	10·8	10·6	13·5	13·5
Straw	14·1	13·7	21·9	23·2
Wheat (6 years C.,) Grain	14·8	14·1	10·8	11·7
„ (5 years D.) Straw	21·5	21·7	15·6	18·0

[1] Series D. had been intended as a check to Series C., but the roots failed in 1921, hence no feeding with cake or corn could be carried out.

It will be seen that there was no difference in the yields given by cake and corn feeding on either crop. Series C. and Series D. are not comparable, as the years to which they refer are different.

The failure to bring out any difference between cake and corn could not be explained by supposing that the land (as in the First Period) was already producing its maximum crop, for, in 1919, the continuous barley (farmyard manure plot) yielded 28·3 bushels per acre, and in 1923 21·8 bushels per acre, both considerably in excess of the figures recorded in the Table above.

Supplementary Experiment in Lansome Field.

From 1885 to 1903 the experiment was repeated with certain modifications in Lansome Field. The same four-course rotation was followed, the roots were fed off by sheep and cake-fed or corn-fed manure was used as in Stackyard Field, but on two additional plots decorticated cotton cake and maize-meal respectively were spread on the land as manure.

There were thus six plots each ¼ acre in size; two received no manure; on two, cake and meal respectively were fed to sheep eating the root crop; and on the other two the cake and the corn meals respectively were spread on the land.

But this experiment proved even less satisfactory than that in Stackyard Field. The soil is very variable and the duplicate unmanured plots did not agree sufficiently well to allow of reliable deductions being drawn. It can only be said generally that decorticated cake applied direct to the soil gave greater crop increases than maize-meal, but between the manurial effects of cotton cake and maize-meal fed to sheep on the land there was very little difference.

Conclusion.

A review of the results forces one to the conclusion that the experiments have entirely failed to show any marked superiority of cake feeding over corn feeding on this soil.

The most that can be said is that the barley immediately following the folding showed a small advantage for cake as against corn. But no subsequent crops benefited. The highest gain in barley from cake feeding did not exceed 6 bushels per acre, and even when (as in the Sixth Period) there was as much difference as the equivalent of 2 cwt. of nitrate of soda between the cake and corn feeding, the crop difference only came to 1 to 2 bushels per acre of barley.

These experiments afford no support to the values assigned in the present Tables, according to which a farmer feeding cake on his land can claim from an incoming tenant compensation at the rate of £3 2s. 11d. for every ton of decorticated cotton cake so used, as against 14s. 9d. for each ton of maize-meal similarly used.[1]

No explanation can as yet be given of the failure to recover the added fertilizer constituents. It was at first supposed that the feeding on the land was too liberal and the crops too large to indicate any differences between the higher and the lower manuring. But when the feeding was reduced and only given once in the rotation, the differences were not more strongly marked, not even when growing barley without manure for a number of years. The substitution of green crops for clover in 1905 did not help though the wheat crop following the clover had been larger than that following the mustard. Even when the difference in nitrogen between the cake and the corn was raised to the equivalent of 2 cwt. per acre of nitrate of soda, there was nothing material to show for the addition.

[1] 1926 figures. In 1876 the figures were £6 10s. for decorticated cake and £1 11s. for maize-meal.

The results cannot be put down to the poverty of the soil in lime; for the whole area received lime at different times. The root crops occasionally failed, but this was due to seasonal conditions and in no case to "finger-and-toe."

Nor can it be said that the experiment was not conducted on practical lines, for the rotation was the ordinary four course one as commonly practised in the district on that class of land.

Further—more especially after 1911—the experiment was conducted, not on small plots, but on plots of 2 acres each, so that the sheep ate the roots with cake or corn just as in ordinary farm practice. Indeed, except for the weighing and recording, the rotation experiments faithfully represented the customary folding of roots with cake or corn; it was as nearly a practical test of the manurial values of cake and corn fed on the land as one could well suggest.

Must we then suppose that the Tables, allowing, as they do, very different unexhausted manurial values to the two materials, are incorrect and not borne out in practice? Or, was there some elemental feature, either in the nature of the Stackyard Field soil or in the experiment, which militated against its success? Or, may there be something in the nature and action of the nitrogen returned to the land which still requires to be explained, and for want of which knowledge the nitrogen, though known to have been passed on to the land, has not been made available for subsequent crops?

It is to this latter view that one who has studied the question in all its bearings, and, along with this, the results of the green-manuring experiments (the description of which will follow), will surely come.

It is universally acknowledged by practical men that cake feeding enriches the land more than the feeding of corn, and yet it may quite well be that, on certain soils and under certain circumstances, this difference of value is not forthcoming.

All said and done, there remains the fact that much more nitrogen has gone into the land by the use of the cake than by that of corn, and yet, for some reason or other, it has not become available for use. What has become of it and how to make it available, or to prevent its loss in the soil, is the work of scientific investigation. In the pursuit of such enquiry the experiments here recorded can hardly fail to serve a purpose.

CHAPTER III.

THE CONTINUOUS GROWTH OF WHEAT ON THE SAME LAND

THESE experiments were designed as a repetition of the more important of the Rothamsted experiments, to see whether the results would be similar on the lighter soil of Woburn.

The general arrangement of the plots consisted of four strips running from one side of the field to the other; the first, divided into 3 plots, had no nitrogen, and comprised the two unmanured plots and the mineral manures (only) plot; the second strip received nitrogen as ammonia salts, either alone, or in different quantities along with mineral manures (3 plots); the third strip, also of 3 plots, received nitrate of soda as the source of nitrogen, while the fourth (2 plots) received organic nitrogenous manures (farmyard manure and, later, rape cake). Hence, on looking down the field, one could see in succession the effects of (*a*) no nitrogen, (*b*) nitrogen as ammonia salts, (*c*) nitrogen as nitrate of soda, (*d*) nitrogen in organic form. The whole was laid out on the plan previously adopted at Rothamsted, but with certain modifications which experience had shown to be desirable.

Each plot was $\frac{1}{4}$ acre in area. As the work developed, it became necessary to divide some of them, and, in the end, no less than seven of the wheat plots were subdivided and eight of the barley. In no case, however, was the plot area reduced below $\frac{1}{16}$ acre. On the land occupied by these plots there had been grown, in 1876, by the previous tenant, a wheat crop which yielded $25\frac{1}{2}$ bushels of corn and $20\frac{1}{2}$ cwt.

of straw per acre. The first experimental crop was grown in 1877.

Varieties Grown.

The varieties of wheat grown at different periods during the 50 years were "Browick" (red), 1877–97; "Stand-up," 1898; "White-chaffed Browick," 1899, 1900; "Street's Imperial," 1901, 1902, 1909; "Grey-chaffed Browick," 1903; "Square-head's Master," 1904–8 and 1910–12, 1914; "Red Standard," 1913, 1915–17, and 1922–24; "Little Joss," 1918–20; "Yeoman," 1921, 1925, 1926. Of the varieties, Browick, Square-head's Master, Red Standard, and Little Joss seemed to be the best.

As a rule, a change of seed was made every fourth or fifth year. The quantity of seed sown per acre was 9 pecks[1] until 1904, when it was increased to 10 pecks, and in 1924 to 12 pecks per acre. The seed was always dressed, as a rule with sulphate of copper, occasionally with formalin, and in later years with corvusine. In the earlier years the seed was dibbled-in by hand, but, later on, this was replaced by the drill.

The plots at an early stage had to be enclosed with a high wire fence, to keep out the deer from the neighbouring woods. The field, being just outside Woburn Park, was very subject to the ravages of pheasants, and required much watching in consequence. The weakest plots were always most attacked, backward and imperfect germination providing more seed grain for the birds to pick out than when germination was more rapid. In the later years this was specially notable with the plots receiving sulphate of ammonia and no lime.

Application of Manures.

Mineral manures were put on just previous to sowing. Sulphate of ammonia and nitrate of soda went on in spring,

[1] 4 pecks = 1 bushel.

as top-dressings—the heavier dressings in two applications; they were mixed with two to three times their bulk of dry sand in order to secure better distribution.

Rape-dust was generally applied about February; for the first few years farmyard manure also was given as top-dressing in spring, but later it was ploughed in before sowing.

Among the most important elements in securing a good yield were a good seed-bed and a good start, with a favourable period for germination. Later on, good tilth and freedom from weeds had much to do with a successful crop, and here was experienced one of the difficulties of continuous wheat growing. The short period that elapsed between the reaping of one crop and the sowing of the next was hardly sufficient to ensure the proper tilling of the land and the destruction of the weeds which thrive so freely when the same crop is grown year after year on the same land. The importance of early hand-hoeing of experimental plots can hardly be exaggerated, and failure to attend to this at the right time was inevitably followed by a reduced yield.

Effects of Manurial Treatment.

No Manure (Plots 1 and 7).

Two unmanured plots were set up, and from the general agreement between them it was assumed that the soil was practically uniform over the whole area. Over each 10-year period the differences of corn yield between Plots 1 and 7 were, in bushels per acre, only 0·6, 1·8, 1·5, 1, and 0·7 respectively. The higher produce was, in each case, given by Plot 7, which was at the top end of the field, whereas Plot 1 at the lower end was more subject to damage from hares and rabbits. Occasionally, when damage of this kind was specially notable, in computing the averages the better plot alone has been taken into account.

Starting with an average of 17·1 bushels for the first 10 years, the produce for each successive period was 13·6, 10·1, 9·9, and 7·1 bushels, the respective falls being 3·5, 3·5, 0·2, and 2·8 bushels per acre during the 50 years. The fall during the 5th period was considerably in excess of the earlier fall—but this may be seasonal; there was hardly a good wheat year from 1921 to 1926. The average for this period was 5·1 bushels only as compared with 14 bushels per acre in 1918.

Despite the falling-off in bad seasons, it may be concluded that even unmanured land cropped continually with wheat will, over a period of 50 years, never become incapable of bearing a crop. After the first decline of about 3 bushels per acre in successive 10-year periods, a point is reached beyond which the yield falls but little further.

Mineral Manures Only (Plot 4).

The average yields of grain for the five 10-year periods, as compared with the unmanured plots, were, in bushels per acre :—

	Plots.	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Unmanured .	1 and 7	17·1	13·6	10·1	9·9	7·1
Mineral manures alone	4	17·7	12·6	8·2	8·6	8·3

The manures used without nitrogen exercised no benefit upon the wheat crop. Nor was any practical difference found when, in 1905, a simpler manuring was adopted and the soda and magnesia salts omitted. The fall in yield over each 10-year period was, with the exception of the last (1917–26), much the same as on the unmanured plots. Plot 4 was possibly at some disadvantage as compared with the unmanured plots, in being near a dividing hedge partly overshadowed by trees; it generally looked decidedly better than the unmanured plots at first, but, as the season went on, this

advantage disappeared. Also coltsfoot grew more abundantly on this plot than on any other, and was most difficult to deal with owing to the short period available for cleaning the land.

Sulphate of Ammonia (Plot 2).

For the first 30 years, i.e. to 1906, the ammonia salts (sulphate of ammonia and muriate of ammonia in equal weights) were given in quantity to supply 50 lb. ammonia per acre. The original intention had been simply a comparison with the equivalent quantity of nitrate of soda. But, as events proved, many and very striking results were the outcome of the continued use of sulphate of ammonia, and these led to a considerable extension of the enquiry, the subdivision of the plot, and the application of lime. After the first 20 years, indeed, the interest centred, not in the yield, but in other points, of which the most prominent were the effect on the soil, the almost entire failure of crop in absence of lime, and the restoration of fertility by the application of lime.

For the first 20 years sulphate of ammonia (ammonia salts as it was then) gave yields considerably greater than on the unmanured plot, and practically equal to those obtained

TABLE 8.—THE EFFECT OF NITROGENOUS FERTILIZERS ON YIELD OF WHEAT.

	Plot.	1877–86.	1887–96.	Increase over Unmanured 1877–86.	Increase over Unmanured 1887–96.
Unmanured . .	1 and 7	17·1	14·0		
Ammonia salts . .	2	25·4	22·2	8·4	8·6
Nitrate of soda . .	3	24·1	24·2	7·0	9·6
		Straw, cwt. per Acre.			
Ammonia salts . .	2	24·7	20·0	7·1	7·2
Nitrate of soda . .	3	25·2	22·2	7·6	9·4

from nitrate of soda (also used by itself), the differences being due more to season than to anything else.

The yields for the first 20 years in bushels per acre are given in Table 8.

Up to 1896 there had been no great decline on Plot 2, though at times—as in 1892 and 1893—the produce fell to 11·4 and 9·3 bushels; but, the corresponding barley plot having meantime gone down even more, it was decided to lime the wheat plot also and to divide it into 2a and 2b, leaving 2a to continue as before, but to give 2 tons per acre of lime to 2b as well as its ammonia salts. This was in December, 1897, and although the wheat was already up, the lime apparently did no damage.[1]

The produce on the unlimed plot continued to fall slowly till 1900, when it was 12·5 bushels as against 17·8 bushels on the limed half, but after this came a rapid decrease with almost total failure of crop, the yields being in bushels per acre, 0·6 in 1901, 4·9 in 1902, 7·1 in 1903, and in 1904 and 1905 no crop whatever. Since then only very occasionally could a crop be reaped and weighed, the highest figure reached has been 3·5 bushels, and out of the 23 subsequent years 16 have been blank.

On the limed plot 2b, 31·5 bushels of wheat were obtained in the first year (1898) after application as against 27·8 bushels on 2a, 29 bushels in 1899 and 17·8 in 1900 as against the 19·1 and 12·5 of 2a. Later on the contrast was even more strongly shown, for while, as stated, sixteen crops of twenty-three failed altogether on 2a, none failed on 2b, even up to 1926, although no more lime was added.

The averages for the 3rd, 4th, and 5th periods were in bushels per acre:—

	1897–1906.	1907–1916.	1917–1926.
Plot 2a (unlimed) .	8·7	0·5	0·5
,, 2b (limed) .	16·8	15·6	7·8

[1] The lime used was best Buxton lump lime, it was slaked with water under cover, then at once carted out and spread over the plot.

It is indeed remarkable that a single dressing of 2 tons of lime per acre should show its influence for 29 years.

The unlimed plot soon became covered with spurrey (*Spergula arvensis*) which persisted in spite of hand-hoeing. None occurred, however, on the limed plot till near the end of the period.

It was thought at first that the wheat plants were actually killed, but closer examination showed they were not. The plants came up and survived to the end of the season; but they quickly turned yellow, and neither tillered nor developed healthy roots.

The soil was found to be acid, and laboratory experiments traced this acidity to the increased loss of lime by leaching caused by the ammonium salts—especially the muriate—though even nitrate of soda had brought about some loss. The colour of the soil also became lighter, though its permeability was not affected, in contradistinction to nitrate of soda, as shown later.

There was little doubt that the acidity had damaged the crop. In 1906 both plots were divided into two: the unlimed part 2aa received 5 cwt. of lime per acre and the limed part 2bb received a second 2 tons of lime per acre, making 4 tons in all since 1897.

The 5 cwt. of lime on 2aa produced an immediate effect which continued for a second year, but no longer. In 1906 the yield was 19·2 bushels per acre, and in 1907 10·5 bushels, but in 1908 3 bushels only, while 2b gave 22·9 bushels. Further dressings of 5 cwt. were therefore given in 1909, 1910, and 1912, thus making 1 ton per acre in all. These dressings enabled the crop to grow, though by 1924 the yield again went down to about 3 bushels per acre.

The additional 2 tons per acre of lime on 2bb caused no increase in yield, although it usually made the crop look better in the early days of growth. The average yields in bushels per acre are given in Table 9.

TABLE 9.—THE EFFECT OF LIME ON ACID PLOTS.

	9 years, 1898–1906.	11 years, 1907–1916.	10 years, 1917–1926.
2a (no lime)	8·7	Nil	Nil
2aa (1 ton lime per acre—in 5 cwt. lots, 1906, 1909, 1910, 1912) .		11·4	6·9
2b (2 tons lime per acre, Dec. 1897)	16·8	15·6	7·8
2bb (as 2b, but with 2 tons lime per acre repeated in 1905) . .		13·7	8·7

The results indicate that the influence of 1 ton of lime per acre (2aa) persisted for about 15 years, and that of 2 tons per acre (2b) for 25 years, the effective benefit being for about 5 years less in each case.

Sulphate of Ammonia and Mineral Manures (Plot 5).

Until 1905 the mineral manures included soda and magnesia salts as well as potash and phosphates, but in 1905 they were simplified to 3 cwt. superphosphate and ½ cwt. sulphate of potash per acre, ammonia also being reduced to 25 lb. per acre. The failure seen on Plot 2 after 20 years did not appear on this plot, the effect of the minerals apparently being to keep the crop "going." Nevertheless, the plot was subdivided, simultaneously with Plot 2, and, while 5a was left without lime, 5b received 1 ton of lime per acre in 1905.

The wheat crop on the unlimed part (5a) never absolutely failed, though its yield decidedly diminished after the first 30 years. Blank patches began to appear in it, and, from 1907, the yield was distinctly inferior to that of the limed half (5b). The lime showed a marked influence up to 1922, so that the 1 ton per acre of lime lasted for quite 15 years, for the first ten of which the benefit was marked. A further 1 ton of lime per acre was given in 1924.

The yields of grain, in bushels per acre, are given in Table 10.

TABLE 10.—THE EFFECT OF MINERAL FERTILIZERS AND LIME ON THE DETERIORATION CAUSED BY SULPHATE OF AMMONIA.

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Sulphate of ammonia alone . . .	25·4	22·2	8·7	0·5	0·5
Sulphate of ammonia with minerals . .	31·5	20·0	24·4	15·8	0·4
Sulphate of ammonia with minerals and lime	—			22·1	13·2

During the period before acidity and crop failure set in, the minerals increased both the weight per bushel of the corn and the straw yield :—

	1877–1886.		1887–1896.	
	Weight per Bushel, lb.	Straw, cwt. per Acre.	Weight per Bushel, lb.	Straw.
Without minerals .	54·4	24·75	58·1	20·0
With " . .	57·8	31·75	59·7	26·0

Plot 8. Ammonia Salts (double quantity) with Mineral Manure as on Plot 5.

The first intention of this plot was to see whether doubling the amount of nitrogen would give a commensurate return. This plan was carried on for the first 5 years, and then in 1882 the plot was divided into halves, 8a and 8b, each of which received the dressing only in alternate years, one receiving it one year and the other in the next. The purpose was to ascertain the result of leaving off the application of ammonia salts for a single year. This question will be discussed later.

So far as the comparison between Plots 5 and 8 can be fairly carried, the yields of grain are, in bushels per acre :—

	Plot.	1877–1886.	1887–1896.	1897–1906.
Single dressing ammonia salts (50 lb. ammonia) with minerals	5	31·5	29·0	24·4
Double dressing ammonia salts (100 lb. ammonia) with minerals	8	38·8	35·5	23·4

The effect of doubling the nitrogenous dressing was to give an increase of 6 to 7 bushels of corn per acre; the weight per bushel was, however, not raised. In the straw the increase was from 5 cwt. to 10 cwt. per acre.

After 1904 there was a rapid fall with the heavier dressing, even more pronounced than with the lighter one. The mineral manures had thus delayed, though they had not prevented, the setting in of crop failure. It was therefore decided to subdivide the plots and apply to 8aa and 8bb 10 cwt. of lime per acre in 1905, thus providing over Plots 2, 5, and 8 a series of lime dressings of 5 cwt., 10 cwt., 1 ton, 2 tons, and 4 tons per acre.

Plot 8a (without lime) continued to get poorer, and after 1913 frequently failed entirely; the average corn yield for the period 1907 to 1916 was 4·8 bushels only. The limed half, 8aa, however, at once responded, giving for the 13 years 1905 to 1917, an average corn yield of 17·6 bushels. A decline had begun to set in, and accordingly in 1917 a further 10 cwt. of lime per acre was given. This immediately raised the yield, and the average for the next 9 years, 1908 to 1916, was 10·2 bushels, as against 3·7 bushels on 8a (without lime).

The first 10 cwt. per acre of lime had been economically effective for 9 years, but the second application of 10 cwt. only for 5 years. The lime increased the yield of straw but not the weight per bushel of the grain.

Nitrate of Soda (Plot 3).

On this plot nitrate of soda was applied every year for the whole period. For the first 30 years the dressing was

equivalent to 50 lb. ammonia per acre (about $2\frac{1}{2}$ cwt.); in 1907, however, the plot was divided, 3a continuing to receive the full dressing while 3b had only half the quantity.

In marked contra-distinction to the sulphate of ammonia plots there was no failure of crop whatever, right up to the close, whether the heavier or the lighter application had been made. The decline in crop was, indeed, much less than on the unmanured land, and did not exceed 9 bushels per acre over the whole 50 years.

The yields of grain for successive 10-year periods were, in bushels per acre :—

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Heavier dressing (≡ 50 lb. ammonia) . .	24·1	23·2	17·0	17·7	15·3
Lighter dressing (≡ 25 lb. ammonia) . .	—			16·0	13·3

In spite of this small deterioration the crops were not altogether satisfactory. They were always the most subject to "rust" and the corn of the poorest quality; the weight per bushel was, without exception, the lowest of all the plots, and the proportion of "tail corn" the highest. Moreover, the land was more prone to weeds, including coltsfoot, though spurrey did not appear to any extent. The physical nature of the soil changed, forming, after rain, a slimy, sticky surface which held up the water and gave a dark-coloured appearance to the plot.

The heavier dressing of nitrate only gave an additional 2 bushels of corn per acre.

The laboratory experiments showed that nitrate of soda did not so readily remove lime from the soil as ammonia salts, and this was borne out in the cropping.

Nitrate of soda and sulphate of ammonia in equivalent dressings gave practically the same yields of grain for the first 20 years (p. 30); though the ammonium salts gave somewhat higher weight per bushel, and the nitrate of soda

rather higher yields of straw. Nitrate of soda usually did better in a dry season and ammonia salts in a wet one:—

GRAIN PER ACRE.

	Dry Seasons.				Wet Seasons.			
	1881, bush.	1883, bush.	1887, bush.	1890, bush.	1877, bush.	1879, bush.	1882, bush.	1889, bush.
Ammonia salts .	31·7	22·1	26·1	24·7	34·5	14·7	32	26·3
Nitrate of soda .	41·0	27·5	35·0	31·2	31·0	12·0	20	18·9

Nitrate of Soda with Mineral Manures (Plot 6).

On this plot there has been no failure of crop all through the 50 years, and the addition of the mineral manures increased the yield: the results are given in Table 11.

TABLE 11. INFLUENCE OF NITRATE OF SODA AND MINERAL MANURES ON YIELD OF WHEAT.

BUSHELS OF GRAINS PER ACRE.

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Nitrate of soda alone .	24·1	23·2	17·0	15·1	13·3
Nitrate of soda with minerals . .	32·4	30·1	23·6	17·5	16·1
Increase due to minerals	8·3	6·9	6·6	2·4	2·8

The manuring with minerals produced a greater weight per bushel of corn and also more straw, as shown in Table 12.

TABLE 12. EFFECT OF MINERAL FERTILIZERS ON THE BUSHEL WEIGHT OF GRAIN AND YIELD OF STRAW.

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
	Grain, Weight per Bushel. Lb.				
Without minerals .	54·7	55·7	57·2	57·6	58·1
With ,, .	57·7	57·9	59·6	58·6	58·0
	Straw, cwt. per acre.				
Without minerals .	25·1	22·1	18·2	15·0	12·3
With ,, .	34·2	28·1	22·2	17·1	14·3

Nitrate of Soda (double quantity) with Mineral Manures (Plot 9).

This was the counterpart of Plot 8 (ammonia salts), and a similar division into 9a and 9b was made after the first 5 years, in order to see the effect of leaving out the nitrogenous application for a single year. Since the question of liming did not come in, there was no further division into limed and unlimed halves. As on the ammonia plots, the nitrogenous dressings were halved after 1907.

The yields of grain were in bushels per acre :—

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Nitrate of soda, light dressing with minerals	32·4	30·1	23·6	17·5	16·1
Nitrate of soda, heavy dressing with minerals	37·2	30·8	20·2	15·1	15·2

The marked effect of the combination of nitrogenous and mineral manure in raising the yield of wheat is shown in Table 13.

TABLE 13.—THE EFFECT OF MINERAL MANURES IN COMBINATION WITH NITRATE OF SODA ON YIELD OF WHEAT.

	Increase over Unmanured Plots.			
	1877–1886, bushels.	1887–1896, bushels.	1897–1906, bushels.	Average of 30 years, bushels.
Plot 3. Nitrate of soda alone . . .	7·3	10·5	7·7	8·5
Plot 4. Mineral manures alone . . .	Nil	Nil	Nil	Nil
Plot 6. Nitrate of soda and mineral manures	15·6	17·4	14·3	15·8
Plot 9. Nitrate of soda (double quantity) and mineral manures .	20·4	18·1	19·1	19·5

The heavier dressing of nitrate of soda gave an additional 2 to 10 cwt. per acre of straw, but hardly affected the weight per bushel of the corn.

Though there was no failure of crop, a marked decrease of yield set in as the years went on, more especially with the heavier dressing, the decline being greater than with minerals only (Plot 4). Moreover, these plots became specially weedy, and the corn was often "rusted" and difficult to reap.

CONCLUSIONS.

(1) Even on the light soil at Woburn wheat could be grown year after year on the same land without manure. It was difficult to keep down weeds, but so long as this was done the yield did not fall below about 8 to 10 bushels per acre. Mineral manures used alone did not increase the yield.

(2) Nitrate of soda and ammonia salts used alone increased the yield. Amounts supplying equal quantities of nitrogen were equally effective over a period of 20 years: the single dressing supplying 41 lb. nitrogen per acre without minerals gave about 9 bushels per acre more grain than the unmanured produce. In a dry season nitrate of soda as a rule, did the better, in a wet season ammonia salts.

(3) In later years halving the dressing of nitrate of soda ($1\frac{1}{4}$ cwt. per acre instead of $2\frac{1}{2}$ cwt.) only reduced the crop by about 2 bushels of corn per acre.

(4) Nitrate of soda produced a poorer grain than ammonia salts, weighing less per bushel and giving more "tail corn." The crop was more liable to "rust," and weeds, coltsfoot in particular, grew more freely.

(5) On the other hand, nitrate of soda gave 1 to 2 cwt. per acre more straw than sulphate of ammonia.

(6) Addition of mineral manures enhanced the yield of grain and of straw from the nitrogenous manures, and also increased the bushel weight of the grain.

(7) Sulphate of ammonia exhausted the soil of lime and made it acid; after about 20 years (the initial lime content having been 0·25 per cent CaO) the crop failed. Mineral

manures delayed, but did not prevent, the setting in of crop failure.

(8) Nitrate of soda had no such effect. It induced changes in colour and texture, however; the soil becomes darker, more clay-like in appearance, and tends to hold up the water more.

(9) No scheme of artificial manuring, however, sufficed to maintain yields indefinitely: as years went on there was a marked falling off.

(10) The acidity and failure to produce a crop, resulting from the repeated use of sulphate of ammonia on a lime-poor soil, was remedied by the application of lime. One ton of lime per acre effectively benefited the wheat for about 10 years, and 2 tons per acre for 15 to 20 years. A larger dressing gave no greater benefit.

(11) So long as sufficient lime is supplied there is no reason why sulphate of ammonia and minerals should not be given for a wheat crop even on a lime-poor soil without any fear of exhausting the land. The resulting yield is about equal to that obtainable from nitrate of soda with minerals.

The Residual Value of Sulphate of Ammonia and Nitrate of Soda (Plots 8a, 8b, 9a, 9b).

This question is of practical importance in connection with the assessment of compensation payable to an outgoing tenant for fertilizers and manure that he has applied and for which his successor will reap some of the benefit.

Plots 8 and 9 were each divided in 1882 into halves, each of which received the same mineral manures every year, but only one of them received the nitrogenous manure, the dressing being given alternately, so that the half that had it one year did not receive it the next. It was thus possible to ascertain what if any manurial value was left over from a single application of ammonium salts, and of nitrate of soda.

For convenience of tabulating, the half-plots that had

the nitrogenous application are called the *a*'s, while those that did not have it are termed the *b*'s; but the particular piece of ground that was *a* one year became *b* the next year, and *vice versa*.

For the first 30 years (up to 1906) the manures were given at the rate of 100 lb. ammonia per acre, but after that the dressings were halved.

The yields of corn up to 1903 in bushels per acre are given in Table 14.

TABLE 14. RESIDUAL EFFECTS OF SULPHATE OF AMMONIA AND OF NITRATE OF SODA.

	Ammonia Salts (Plot 8).			Nitrate of Soda (Plot 9).		
	1882–1891.	1892–1901.	1902–1903.	1882–1891.	1892–1901.	1902–1903.
Salts applied (*a*) . .	38·8	35·5	27·5	37·2	30·8	29·2
Salts omitted (*b*) . .	20·4	24·5	19·7	17·1	16·1	11·8
Diminution due to omission	18·4	11·0	7·8	20·1	14·7	17·4
Unmanured produce (Plot 7)	17·4	14·5	10·8	17·4	14·5	10·8
Increase due to residue remaining . . .	3·0	10·0	8·9	−0·3	1·6	1·0

With the falling-off in corn due to the omission of the nitrogenous salts goes, naturally also, a corresponding fall in the straw yielded. On 9b (after nitrate of soda) the yield of straw went down nearly to the unmanured level, the increase being less than 1 cwt. per acre, but on 8b (after ammonia salts) it remained 5 cwt. per acre higher. Nitrate of soda clearly left nothing over after the first year, thus justifying the practice in valuation of unexhausted residue of making no allowance for nitrate of soda beyond the year of application. On the other hand, ammonia salts apparently left a small residue which, though not really material, tended to rise as the years went on.[1]

The weight per bushel of the corn was much the same on Plot 8 whether ammonia salts were given or not, but on

[1] But see p. 159.

Plot 9 the omission of nitrate of soda raised the bushel weight about 1 lb.

Phosphate and Potash as Mineral Applications (Plots 10a, 11a).

The purpose of this experiment was to ascertain whether phosphate or potash was the more important mineral manure for wheat on this light soil. It formed no part of the original scheme, but was started in 1907 on two plots, both of which had previously received farmyard manure though at some long interval. Each plot received nitrate of soda (20·5 lb. nitrogen per acre); 10a received 3 cwt. of superphosphate and 11a 1 cwt. of sulphate of potash per acre.

The yields per acre were :—

	1907–1916.		1917–1926.	
	Corn, bushels.	Straw, cwt.	Corn, bushels.	Straw, cwt.
With superphosphate . .	17·3	16·0	13·0	13·15
With sulphate of potash . .	15·5	15·05	13·4	13·1
Plot 6 (mixed mineral manures)	17·5	17·0	16·1	14·15

There is practically no difference in effect between phosphate and potash, though the balance is slightly in favour of phosphate. In neither case was quite so high a yield obtained as with mixed mineral manures. There was no difference as regards weight per bushel of corn.

Farmyard Manure (Plot 11b), and Rape Cake (Plot 10b).

The application of a light dressing of farmyard manure (Plot 10) had not been satisfactory, and so it was discontinued; but the heavier dressing (200 lb. ammonia per acre) on Plot 11 gave more or less consistent results from the

outset: it was therefore continued to the end, the only change being that in 1907 the dressing was reduced (p. 350).

From 1890 Plot 10 was given rape cake, at that time a common manure, especially in Norfolk: the dressing was equivalent to 100 lb. ammonia per acre, reduced in 1907 to 25 lb. ammonia per acre. This was applied in February, and immediately showed an effect on the wheat.

The yields per acre are given in Table 15.

TABLE 15. EFFECT OF RAPE DUST AND FARMYARD MANURE ON YIELDS PER ACRE OF WHEAT, 1890–1926.

	1890–1896.		1897–1906.		1907–1916.		1917–1926.	
	Corn, bush.	Straw, cwt.	Corn, bush.	Straw, cwt.	Corn, bush.	Straw, cwt.	Corn, bush.	Straw, cwt.
Rape dust (100 lb. ammonia to 1906, then 25 lb.) . .	27·2	24·2	26·6	25·2	18·8	16·2	12·6	11·3
Farmyard manure (200 lb. ammonia to 1906, then 100 lb.)[1] .	27·8	25·2	24·0	24·2	19·6	21·1	17·7	19·0

The returns from the larger dressing of rape cake are quite as good as from farmyard manure, supplying double the amount of nitrogen. The reduced dressing of rape cake, however, was much less effective.

It was in a dry season, naturally, that farmyard manure told most, as it helped to retain moisture in the land. This may be illustrated by the following yields per acre:—

	Dry Seasons.			Wet Seasons.		
	1881.	1883.	1887.	1887.	1879.	1882.
Yield of corn, bushels .	41·2	33·5	36·9	18·9	18·7	21·2
Yield of straw, cwt. . .	32·15	37·05	31·1	20·1	24·0	30·15

[1] See p. 351.

At the same time, the continued "opening" effect produced by straw manure kept the soil very loose, and it is questionable whether, on the whole, this is beneficial. This plot was always very prone also to the growth of weeds. Nevertheless, taking the series of years, farmyard manure gave the second highest yield, being exceeded only by the very highly manured Plot 9 (nitrate of soda and minerals). Indeed in the 5th period (1917–26) it proved superior, its average corn yield (17·7 bushels) being 1 bushel more per acre than from any other plot, and the soil had evidently suffered least exhaustion; the fall from the 1st period (26·7 bushels) to the last (17·7 bushels) being 9 bushels only.

Conclusions.

(1) Farmyard manure of good quality yielded larger wheat crops, both of corn and straw, than any ordinary dressing of artificial manures.

(2) The advantage was seen on light land more particularly in a dry season.

(3) Rape-dust proved an effective manure for wheat on this light land, giving, both in corn and straw, results but slightly inferior to those given by farmyard manure containing double the quantity of nitrogen.

CHAPTER IV.

THE CONTINUOUS GROWTH OF BARLEY ON THE SAME LAND.

THE continuous barley experiments were laid out on exactly the same lines as the continuous wheat experiments and the results are essentially the same. The differences are associated with the soil rather than with the manures or the crops. The soil, being a sandy loam, with comparatively little clay, was better suited for barley than for wheat, hence the unmanured produce for the first 10 years was 26·9 bushels per acre of barley, but only 16·8 bushels of wheat.

On the other hand, the exhaustion of lime and production of acidity affected the shallow-rooting barley sooner than the wheat, and lime had to be applied in larger amounts and in greater frequency.

The barley possessed a great advantage over the wheat in that the late autumn and early winter were available for cultivating and cleaning the land; the weeds could therefore be better controlled and a better seed-bed obtained.

The prevalent weeds on the barley plots differed somewhat from those on the wheat, spurrey being the most generally abundant, especially on the acid plots, horse-tail (*Equisetum arvense*) also occurred, but coltsfoot was less abundant.

The varieties of barley sown were: 1876–82, "Chevalier"; 1883–98, "Golden Melon"; 1899–1900, "Archer's Stiff-straw"; 1901 and 1903, "Standwell"; 1902, "Hallett's Pedigree"; 1904–8 and 1913–19, and 1921, "Chevalier"; 1909–12, "Goldthorpe"; 1920 and 1922–6, "Plumage Archer." The quantity of seed sown was, in the earlier

years, 9 pecks per acre, increased in 1902 to 10 pecks, and from 1924 on 12 pecks per acre. The seed was seldom dressed, though occasionally formalin was used. The manuring was done as for wheat, except that the farmyard manure was spread on the land in January and ploughed in before the barley was sown.

The crops were largely free from special fungoid and insect attacks; in 1922, however, "Gout-fly" badly attacked the plots, the most highly manured being the least affected.

No Manure (Plots 1 and 7).

The duplicate Plots 1 and 7 differed over the 50 years' period only by half a bushel per acre.

The falling-off for the successive 10-year periods is shown by the following yields in bushels per acre :—

1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
25	17·5	12·5	9·5	8

Over the 50 years the decline has been 17 bushels per acre, compared with 10 bushels in the case of wheat.

Mineral Manures (Plots 4, 10a, 11a).

These increased the barley more than they did the wheat —the gains being 1·7, 4·2, 3·7, 3·1, and 2·1 bushels of barley per acre for each 10-year period, while there had been no increase of wheat. Neither the straw nor weight of corn per bushel were materially affected.

Of the mineral ingredients the experiments on Plots 10 and 11 started in 1905 indicated that potash was more important than phosphate :—[1]

	1906–16, per Acre.	1917–26, per Acre.
Plot 10a. Superphosphate and nitrate of soda .	18·5	14·7
Plot 11a. Sulphate of potash and nitrate of soda	23·7	17·0

[1] But see p. 146.

There was a corresponding increase in straw, but no difference in bushel weight of the corn.

In 1915 Plot 4 was divided after receiving phosphate and potash, and 1 ton of lime per acre was given to the part called 4b. An average increase of nearly 2 bushels per acre and a corresponding gain in straw, were obtained over the next 12 years. The quality of the grain, however, was not improved.

Sulphate of Ammonia (Plot 2).

As with wheat there was for the first 20 years a considerable increase of corn from using sulphate of ammonia or nitrate of soda alone. The yields were, in bushels per acre :—

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Plots 1 and 7. Unmanured . .	25	17·5	12·5	9·5	8
Plot 2. Sulphate of ammonia . .	39·4	27·7	3·8	0·3	1·5
Plot 3. Nitrate of soda	40·4	30·9	23·7	15·2	11·3

Between sulphate of ammonia and nitrate of soda supplying equal amounts of nitrogen the difference for the first 10 years was only 1 bushel per acre. By 1893 (i.e. 16 years from the start) the yield from ammonia salts had begun markedly to decline. The plot was therefore divided, and 2 tons per acre of lime given to 2b in December, 1897, just as was done for wheat. The crop at once responded, and rose in 1898 to 16·5 bushels as against 7·6 bushels on the unlimed part 2a ; for the next 9 years its average yield was 21·3 bushels, or only 2 bushels short of the yield from nitrate of soda.

Nevertheless, the lime was not so long effective as for wheat, and in 1905 another 2 tons per acre was given to one half of 2b (2bb). In 1912 a like application was put on the other half of 2b. The crop responded in each case,

and these plots (having now had 4 tons per acre of lime) yielded more or less fairly until the end. One half of Plot 2a (2aa) received small applications of 5 cwt. lime per acre in 1905, 1909, 1910, and 1912, and finally, in 1923 10 cwt. These small dressings partially restored the crop but were insufficient to be really satisfactory.

Sulphate of Ammonia and Mineral Manures (Plot 5).

For full 20 years the yields showed no appreciable falling-off, though without minerals the fall was marked after 16 years. Evidently, therefore, the minerals tended to mask the effects of acidity. Still, as half of Plot 2 was being limed in December, 1897, 2 tons per acre were also given to one half (5b) of Plot 5, and an equal amount again in 1912. The effect was at once seen.

Somewhat later (1905) it was decided to try whether 1 ton of lime per acre would suffice, and 5a was accordingly divided into 5a and 5aa, 1 ton of lime per acre being given to 5aa. This application lasted for another 8 or 9 years, and in 1916 it was repeated. The yields of grain in bushels per acre are given in Table 16.

TABLE 16.—EFFECT OF SULPHATE OF AMMONIA WITH AND WITHOUT LIME, ON THE YIELD OF BARLEY.

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Plot 2a. Ammonia salts alone	39·4	27·7	3·8	0·3	1·5
Plot 5a. Ammonia salts with minerals . .	43·0	35·1	7·2	2·8	4·9
Plot 5aa. Ammonia as 5a, plus lime . .	—	—	—	18·7	16·3
Plot 5b. As 5a, plus lime 2 tons (and repeated)	—	—	33·8	20·3	13·4

As with wheat, the minerals increased the effectiveness of the nitrogen, the average gain being in the first 10 years 3·6 bushels per acre.

Effect of soil acidity on the growth of barley. Permanent Plots, Stackyard Field.

Plot 2A. (right hand). Soil which has become acid.
Plot 2B. (left hand). Soil where the acidity is neutralized with lime.

On the acid plot there is a strong growth of Spurrey (*Spergula arvensis*) which completely hides the diminutive barley plants.

Ammonia Salts (double quantity) with Mineral Manures (Plot 8).

As in the corresponding wheat experiment, Plot 8 was divided in 1882 after the first five crops, ammonia salts being thereafter applied to one half and omitted from the other in alternate years. In 1907, with the general lowering of manurial application, the 100 lb. of ammonia per acre hitherto given was reduced to 50 lb. A further division of 8a and 8b into limed halves 8aa, 8bb, was made in December, 1897, 2 tons per acre of lime being applied to each, and this dressing was renewed in 1912. The yields of grain were in bushels per acre :—

Without Lime.			With Lime.			
	1877–1886.	1887–1896.		1897–1906.	1907–1916.	1917–1926.
Plot 5a (50 lb. ammonia) .	43·0	41·1	Plot 5b (25 lb. ammonia) .	33·8	20·3	13·4
Plot 8a (100 lb. ammonia) .	51·2	39·7	Plot 8aa (50 lb. ammonia) .	38·0	22·7	15·5

In the first period the additional 50 lb. ammonia gave an additional 8 bushels of barley per acre, while in the later years after liming the additional 25 lb. gave an extra 2 to 4 bushels, and 2 to 3 cwt. more straw per acre, but the quality of the grain was unaffected.

The first 2 tons of lime lasted for about 12 years and the second lasted 11 years, without showing any marked falling-off.

Nitrate of Soda alone (Plot 3).

The crop increases given by nitrate of soda and by sulphate of ammonia (so long as the deficiency in lime did not tell) were almost the same, though, as with wheat, the yield was influenced by the wetness or dryness of the season.

Later on, however, the nitrate of soda, unlike the sulphate of ammonia, continued to give crops although the yields steadily fell: they are given below.

In 1907 Plot 3 was divided, and one half, 3b, received henceforward only half the dressing of nitrate: on this the yield was reduced by 1·6 to 2·6 bushels only per acre, not enough to justify the heavier application.

In 1921 each half plot was again divided and 2 tons per acre of lime were applied to the new plots, 3aa and 3bb, but no increase in crop resulted.

Nitrate of Soda and Minerals (Plot 6).

The addition of mineral manures to nitrate of soda put up the yield from 5 to 11 bushels of corn per acre, with a corresponding increase in straw and 1·5 lb. more weight per bushel of corn. The crop continued to be one of the best in the series, though like all the rest it distinctly fell off as the years went on. There was no marked difference between the yield from nitrate of soda and minerals and that from sulphate of ammonia and minerals when sufficient lime was given.

The yields in bushels per acre are given in Table 17.

TABLE 17.—EFFECT OF NITRATE OF SODA IN SINGLE AND DOUBLE DOSE ON YIELD OF BARLEY GRAIN.

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Unmanured . .	25·0	17·5	12·5	9·5	8
Nitrate of soda alone .	40·4	30·0	23·7	15·2	11·3
Nitrate of soda and minerals . .	46·0	41·1	35·3	19·7	16·5
Sulphate of ammonia: Minerals + lime .	—	—	33·8	20·3	13·4
Nitrate of soda and minerals, plot 9 (50 lb.) . . .	53·3	45·3	42·9	25·4	20·0

Doubling the amounts of nitrate of soda gave an increase of 4 to 7 bushels per acre corn and 5 to 6 cwt. straw. The weight per bushel of corn was not, however, improved.

As compared with sulphate of ammonia, the yield of grain was about 4 bushels and of straw about 3 cwt. greater, but the quality of the grain was rather inferior. During the 5th period the yield was only 6 bushels below that from farmyard manure.

The Residual Value of Sulphate of Ammonia and Nitrate of Soda (Plots 8a, 8b, 9a, 9b).

This experiment was begun in 1882, and continued on the same lines as adopted for the wheat. The results are given in Table 18.

TABLE 18. RESIDUAL EFFECTS OF NITROGENOUS MANURES. BUSHELS PER ACRE.

	Sulphate of Ammonia.					Nitrate of Soda.				
	1882–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.	1882–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Salts applied . .	51·2	39·7	38·8	32·7	15·5	53·3	45·3	42·9	25·4	20·0
Salts omitted . .	37·0	28·0	28·3	15·2	11·1	34·5	29·4	23·5	16·4	13·2
Diminution due to omission . .	14·2	11·7	9·7	7·5	4·4	18·8	15·9	19·4	9·0	6·8
Unmanured produce (Plot 7) . .	23·0	18·1	13·4	9·0	7·5	23·0	18·1	13·4	9·0	7·5
Increase due to residue remaining . .	14·0	9·9	14·9	6·2	3·6	11·5	11·3	10·1	7·4	5·7

Over the whole period of 45 years the average yearly residue corresponded to about 9 bushels of corn per acre, and, unlike what happened with wheat, there was no difference between sulphate of ammonia and nitrate of soda.

Rape-dust (Plot 10b).

These results differed somewhat from those for wheat. When used in quantity to supply 100 lb. of ammonia per acre it was nearly as effective as farmyard manure, but after 1907, when the dressing supplied 25 lb. of ammonia per acre only, it gave rapidly reduced yields, as shown below.

Farmyard Manure (Plot 11b).

As with the wheat, farmyard manure gave the highest average yields over the 50-years period, and the falling-off was less marked than on the other plots. The yields in bushels per acre are given in Table 19.

TABLE 19.—EFFECT OF FARMYARD MANURE AND RAPE-DUST ON YIELD OF BARLEY GRAIN, 1877–1886.

	1877–1886.	1887–1896.	1897–1906.	1907–1916.	1917–1926.
Farmyard manure[1] (200 lb. ammonia) .	40·0	38·7	36·6		
Farmyard manure (100 lb. ammonia) .	—	—		30·0	25·0
Rape-dust giving 100 lb. ammonia .	31·1	37·4	33·5		
Rape-dust giving 25 lb. ammonia .	—			17·4	8·6

In the 4th and 5th periods the yields on the farmyard manure plots exceeded those of wheat on the corresponding plots (19·6 and 17·7 bushels only). The quality of the grain on the farmyard manure plots was quite equal to that of the best of the other plots.

CONCLUSIONS.

(1) When barley was grown without manure the yields fell from a 10-year mean of 25 bushels to 12·5 bushels during the first 30 years, and to 8 bushels during the last 20 years of the 50-year period.

(2) Mineral manures without nitrogen increased the yield by 2 to 3 bushels per acre. For wheat there had been no increase. Potash appeared to be more effective than phosphate; wheat had given the reverse results. The addition of 1 ton per acre of lime increased the yield by 2 bushels per acre.

[1] See p. 351.

(3) Sulphate of ammonia and nitrate of soda used in equivalent quantities are almost equally effective in increasing the yield of corn. Quantities supplying 41 lb. nitrogen per acre added on the average 15 bushels annually during the first 20 years.

Addition of mineral manures further increased the effectiveness of the nitrogenous fertilizer, adding a further 5 to 11 bushels per acre.

(4) After about 16 years' treatment with sulphate of ammonia the barley began to fail through acidity of the soil. The barley showed the effects of acidity sooner and more markedly than wheat; it required the application of dressings of lime more frequently.

A dressing of 2 tons per acre of lime acted beneficially for some 11 to 12 years. When the supply of lime and of mineral manures was maintained, sulphate of ammonia gave good crops of barley with no risk of failure, the yields being but little inferior to those produced by nitrate of soda.

(5) Nitrate of soda tends to be somewhat better than sulphate of ammonia for increasing grain and straw, and did not induce soil acidity or any other special soil deterioration. Its effectiveness was not increased by adding lime. The most effective combination of artificial fertilizers was that in Plot 9, receiving the double dressing of nitrate of soda with minerals.

(6) Both sulphate of ammonia and nitrate of soda appeared to leave manurial residues available for barley, and there was no difference between the two. This result differs from that obtained with wheat where sulphate of ammonia appeared to leave a residue but nitrate of soda did not.[1]

(7) Rape-dust proved less satisfactory for barley than for wheat; dressings of about 16 cwt. per acre gave fair barley crops, but 4 cwt. did not.

[1] This apparent residual action could be explained if Plot 4 were not strictly comparable with Plots 8 and 9. See p. 159 (E.J.R.).

(8) Farmyard manure of good quality produced larger crops of barley and with more straw per acre than the highest ordinary dressings of artificial manures. The yields fell off less as the years went on than under any other manuring, and the quality of the corn was as good as from any other plot.

Comparison with the Rothamsted Results.

(1) These experiments on the effect of manures on the growth of wheat and of barley on the light soil of Woburn have in general confirmed the results obtained on the heavier soil at Rothamsted. Such differences as occur are related to the effect of fertilizers on the soil rather than to their effects on the plant.

(2) The Woburn experiments have, however, given wider information in regard to acidity of soil, failure of certain nitrogenous applications, restoration of fertility by the use of lime, and period of duration of lime. This came about because the Woburn soil is poor in lime, while the Rothamsted soil is well supplied with it.

CHAPTER V.

GREEN-MANURING AND GREEN-CROPPING.

THE subject of green-manuring was taken up at Woburn in 1892 as the direct outcome of the work of the German chemist, Hellriegel, whose famous investigations had recently supplied the long-sought-for explanation of how leguminous plants utilised the free nitrogen of the air. The fact that clover, grown as a preparatory crop for wheat, supplied the wheat with what was the equivalent of an application of nitrogenous manure, had long been known to agricultural science and had become a recognised part of good farming practice.

In 1886 Hellriegel and Wilfarth found the explanation. They showed that certain bacteria, living in the roots of the clover plant, fix atmospheric nitrogen distributed throughout the soil, and convert it into compounds that the clover plant can assimilate.

This having been established, Dr. J. A. Voelcker decided to try on the field scale whether other leguminous crops exercised a similar effect.

The experiments were begun in 1892, in Lansome Field, the soil of which is not unlike that of Stackyard Field, though less uniform in character. The crops tested were mustard, rape, and tares. Each was grown on an area of ⅓ acre, but this was subdivided, mineral manures (3 cwt. superphosphate and 2 cwt. kainit per acre) being given to the upper half and nothing to the lower half.

In October, 1904, 1 ton of lime per acre was applied to the lower (no minerals) plots, and in 1907 on the upper half the

2 cwt. of kainit per acre were replaced by 1 cwt. of sulphate of potash. The arrangement was as follows:—

With minerals	6	4	2
No minerals	5	3	1
	Woburn		Farm buildings

Green crops were grown in 1892, barley in 1893, the green crops in 1894, and barley in 1895. This alternation of green crop and corn continued with few exceptions to the end.[1]

The green crop was sown in spring, then when it had grown sufficiently or when flowering was general it was ploughed in and a second green crop sown and subsequently turned in. The rate of seeding has been generally: mustard, 10 lb.; tares, 2 bushels; rape, 8 lb. per acre. Occasionally winter tares have replaced spring tares, but without any apparent difference in result. The rape frequently failed and was given up in 1917; but mustard and tares have grown fairly well.

The average yields were as follows:—

	After Mustard, Bushels per Acre.	After Tares, Bushels per Acre.
Barley, 1893 and 1895	39·3	40·6
Wheat, 1897 to 1903	24·8	16·7
Wheat, 1906 to 1912	24·8	16·1
Average of all wheat crops, 1897 to 1917 .	23·1	16·0

[1] Barley was taken in 1904 after wheat, as a second crop, and oats in 1913, also after wheat, with the object of seeing the result of growing two corn crops in succession, and also to ascertain whether barley and oats behaved differently from wheat.

In each period alike the tares failed to increase the yield of corn as compared with mustard: indeed the yields averaged 7 bushels per acre more after the mustard. Mineral manures raised the corn yield about 2 bushels per acre but did not alter the relative effects of the mustard and the tares.

Nor was the corn crop unsatisfactory up to 1917, for the average yield during the whole period compared—for the mustard plot at least—quite favourably with the produce of wheat on the continuous wheat plots (Stackyard Field) during a like period, this latter being, on Plot 6 (manured yearly with superphosphate and nitrate of soda), 23·6 bushels of wheat per acre. In spite of green-manuring the yields diminished all the time; the original produce of 27 to 29 bushels of wheat per acre in 1899 fell to 15 or 16 in 1915 and to 10 in 1917. There was no evidence of any difference in residual effect: barley in 1904 following wheat in 1903 gave about a bushel more per acre after mustard, while the oats in 1913 after wheat in 1912 showed a difference of 1½ bushels per acre in favour of tares.

These unexpected results led to suggestions being put forward to account for them, and these were severally examined. One was that, though the tares were the more nitrogenous, the greater bulk of mustard believed generally to be obtained might have supplied, in the aggregate, more organic (vegetable) matter and, possibly, as much nitrogen as the smaller crop of tares.

To test this, in 1902 the first green crops of that year were cut, weighed and analysed; this was done again in 1905. The results were:—

1902.	Mustard, lb. per Acre.	Tares, lb. per Acre.
Weight of first green crop . .	6888	8463
Organic matter	1047	13·20
Nitrogen	27·5	60·1

1905.	Mustard.	Tares.
Weight of first green crop, lb. per acre	12054	15498
Moisture, per cent	72·16	73·46
Organic matter, per cent . .	25·53	24·45
Nitrogen, per cent	0·46	1·05

It was clear, therefore, that the tares produced considerably more weight of crop, and supplied the land with more organic matter and much more nitrogen than did the mustard.

During the winter and early spring the wheat after tares looked always the better, and it so continued until the warmer weather set in, after which the wheat after tares began to fall off and more markedly than that after mustard.

This led to another suggested explanation which obtains some support from practical experience, inasmuch as tares are preferred as a green crop on heavy and wetter land, but mustard on a lighter and drier soil (such as that at Woburn). It was thought that, so long as moisture was held in the land, the wheat after tares—having sufficient moisture—did well, but that when the soil began to become dry, and less moisture was retained, the wheat after mustard suffered less.

This suggestion received some confirmation from experiments simultaneously carried out at the Pot-culture Station, which showed that the tares-wheat did as well as that after mustard if it were supplied with water according to its requirements, but it required considerably more water than did the mustard-wheat.

Further, it was noticed that, after harvest, the tares soil was much darker in colour than the mustard soil, and also that it seemed much looser in texture and more open, a difference which was clear when walking over the land after harvest.

In order to see whether the soil had undergone any enrichment in nitrogen, samples were taken from the plots, in 1915, to a depth of 9 inches from the surface. These gave:—

		Original Soil, 1892.	Mustard Soil, per cent.	Tares Soil, per cent.
Moisture		...	7·17	10·75
In soil dried at 100° C.	Organic matter	3·11	2·48	2·61
	Nitrogen	0·13	0·080	0·084

There had been no increase, but rather a diminishing, of organic matter and of nitrogen through the green-manuring, and there was no practical difference in effect between the tares and the mustard.

By 1917 the land had got very foul and it was hard to keep the weeds down. Accordingly, after the wheat crop of that year the land was given a thorough cleaning.

The upper portions of the area having given somewhat irregular results, and being on thinner soil and rising ground, it was decided to continue the experiment on the lower plots only. Three new plots were added, one for tares, one for mustard, and the third was kept as a control plot. These are called the "new" plots. The plan of experiment was as follows :—

	Control Plot.	Tares Plot.	Mustard Plot.	Tares Plot.	Mustard Plot.	
	5	4	3	2	1	
Woburn		New plots		Old plots		Farm Buildings

The land was fallowed in 1918 and 1919. Barley was sown in 1920 but failed. Green crops were sown in 1921 and 1922 and received basic slag, 5 cwt. per acre, 1 cwt. per acre of sulphate of potash. Wheat followed in 1923, and thereafter the green crops and wheat alternated as before. In September, 1923, 2 tons per acre of lime were applied to one half of each plot, but its effect was, if anything, harmful. The separate weighings are accordingly not recorded.

The corn yields in bushels per acre are given in Table 20. The green crops had been quite good and no explanation can be given of the remarkable falling-off of the wheat produce.

When it was seen that the results were contrary to those expected, and that wheat grown after mustard ploughed in was, as a rule, better than that after tares similarly ploughed in, it was suggested that it might be well to see whether the like results would ensue if the green crops, instead of being

TABLE 20.—YIELD OF WHEAT AFTER MUSTARD AND AFTER TARES PLOUGHED IN.

	Old Plots.		New Plots.		
	After Mustard.	After Tares.	After Mustard.	After Tares.	Control Plot.
1923. Wheat	6·9	7·0	7·2	7·2	5·7
1925. ,,	6·9	4·5	4·8	4·5	4·0
1927. ,,	not weighed		8 lb.	24 lb.	20 lb.

ploughed in, were fed-off on the land by sheep. This was accordingly, tried on Stackyard Field, on the 4 acres which had originally formed Rotation I. of the Unexhausted Manurial Value of Cake and Corn Series. The experiment was started in 1911. The same three green crops were grown as in Lansome Field, spring tares, rape, and mustard and the area was divided as follows:—

3a	2a	1a	Lower Half.
Tares	Rape	Mustard	
3	2	1	Upper Half.

Two tons of lump lime per acre were put on the lower half and 1 ton of ground lime per acre on the upper half of the plots. Green crops were grown in the spring of 1911 and fed-off by sheep along with cotton cake; wheat followed in 1912 and thereafter green crops and wheat in alternate years each wheat crop receiving 4 cwt. of superphosphate and 1 cwt. of sulphate of potash per acre. This continued until 1921 when rape was omitted, and the comparison continued with tares and mustard only.

The green crops of both tares and mustard were generally good. One and a half cwt. per acre of undecorticated cotton cake was usually fed, but both the quantity and kind of cake

varied somewhat according to the size of crop and number of sheep put on.

The harvest results for the wheat crop over the period 1912–20 were, in bushels of grain per acre :—

	1912.	1914.	1916.	1918.	1920.
After mustard	18·2	16·1	11·3	15·2	14·2
After tares	18·8	14·2	8·1	12·2	9·7

These figures show a gradual fall in yield of wheat—especially after the tares.

In 1918 the highest yield was no more than that of the unmanured plot of the continuous wheat series on closely adjoining land in the same field. The green crops of 1919 had been exceptionally good, and yet the wheat crop of 1920 was only 9·7 bushels per acre after tares and 14·2 bushels after mustard as against 27·1 bushels in the Rotation experiments. Thus neither an unfavourable season for wheat nor inferior green crops could account for the unexpected falling-off. Moreover, this land had had the benefit of treading by sheep, and had, as a rule, 3 cwt. per acre of cotton cake fed upon it. Nor was it likely that failure had resulted from want of phosphate or potash, as these were applied to each wheat crop. The reason for failure had clearly to be sought in other directions. Here at least was the fact, shown by frequent repetition, alike on Stackyard and Lansome Fields, that the ploughing-in or feeding-off of green crops such as tares and mustard had not merely failed to produce any benefit, but had resulted in much reduced yield of a subsequent wheat crop.

Further, the mustard, though a non-leguminous crop, had produced in both fields a better wheat crop than the leguminous tares—a result the very opposite of what had been expected.

In 1920 the soil was sampled and analysed ; a sample was also taken from the soil on which wheat following red clover had been grown in the adjacent Rotation experiment that same year ; the results are given in Table 21.

TABLE 21.—RESULTS OF SOIL ANALYSES MADE IN 1920.

	Mustard Plot, per cent.	Tares Plot, per cent.	Red Clover Plot, per cent.
Water	11·07	12·05	12·54
Organic matter and loss on heating	5·03	5·02	6·17
Nitrogen	·098	·114	·122
Yield of wheat, bushels per acre, 1920	14·2	0·7	27·1

This, instead of supplying, as had been hoped, an explanation of what had resulted, tended to complicate the matter still further ; for while the higher nitrogen in the red clover soil might be responsible for the much heavier crop of wheat, one cannot understand why the nitrogen in the tares soil, being higher than in the mustard soil, should have failed to produce a corresponding increase. The tares soil was also the richer in organic matter, though hardly equal to the clover soil.

The conclusion was forced on one that in some way, as yet unknown, the three crops, clover, tares, and mustard, differ in character as regards their influence on a succeeding wheat crop, and that, while the nitrogen from clover is available, that from tares and mustard is not : it seems incapable of exercising any benefit, and may have, indeed, a depressing effect.

From 1921 onward rape was omitted, tares and mustard only being retained. Each crop was fed-off, as before, by sheep, these receiving 1½ cwt. per acre of undecorticated cotton cake.

Further, instead of the whole area of 4 acres being covered one year with a green crop and the next with wheat, the plots were divided so that each crop could be grown in the one year, the green crops being grown on one area of 2 acres and wheat on the other ; these were yearly alternated. The plots were :—

Tares plot 2a	Mustard plot 1a	Wheat.
Tares plot 2	Mustard plot 1	Green crop.

Two cwt. superphosphate and 1 cwt. sulphate of potash per acre were applied to each wheat crop ; 2 tons lime per acre were applied in September, 1923, to one-half of each plot of the upper section, and similarly in October, 1924, to one half the lower section. No benefit accrued, however, and the results are not separately set out.

The wheat crop continued to get worse and worse, the yields in 1925 being 5·7 bushels (mustard), and 6·4 bushels (tares) only per acre, as against 25·2 bushels on the Rotation plot (Series C.) in the same field. As before, the wheat was better, as a rule, after mustard than after tares. In the winter and early spring it frequently looked as promising as any on the whole farm, the tares-wheat being usually better than that after mustard. But as summer and warmer weather came on, the plants seemed suddenly to fall off and they ended up as unaccountably miserable crops. The yields for the years 1922 to 1927 were, in bushels of grain per acre :—

	1922.	1923.	1924.	1925.	1926.	1927
After mustard .	7·5	5·6	9·1	5·7	2·8	4·4
After tares . .	6·9	8·0	7·3	6·4	4·6	3·7

In 1921 the wheat after tares was better on the portion that had previously been occupied by rape than on that where tares had followed tares, suggesting that the repetition of the growing of tares had had some injurious effect on the soil.

The whole subject is intricate, and calls for much investigation before a solution can be reached.

CHAPTER VI.

GRASS AND OTHER FODDER CROPS.

WHILE most of the Woburn Farm is too light and sandy to be suitable as permanent grass land, there is some heavier soil on the side further from Woburn Town. Here on Great Hill Bottom field, 7 acres in extent, the grass experiments were begun in 1886.

The Inclusion of Rye-grass in a Seed Mixture.

At that time the "rye-grass" controversy was in full force. One school, led by de Laune, then an active member of the R.A.S.E. Council, and supported by Carruthers, then the Society's Botanist, was strongly opposed to the inclusion of rye-grass in seed mixtures for permanent pastures, and maintained that this was responsible for much of the failure of pastures throughout the country. The other school, headed by Fream, maintained, on the other hand, that the best pastures in England owed their character largely, if not chiefly, to the presence of rye-grass. The question was never satisfactorily decided, for, after an examination of certain of the best grazing pastures in Leicestershire and Northamptonshire for the purpose of ascertaining the relative preponderance of the principal grasses in the herbage, the one school reported that rye-grass was present to but a comparatively small extent, while the other party, examining the same pastures, reported that rye-grass was the most prominent ingredient!

Three plots of 1 acre each and three of ½ acre each were

marked out. Three different seed mixtures, at varying cost but all without rye-grass, were sown on the 1-acre plots, and similar mixtures, but with rye-grass in substitution for other seed and therefore costing less, were sown on the ½-acre plots. The seeding included foxtail, cocksfoot, meadow fescue, tall fescue, timothy, rough-stalked meadow-grass, smooth-stalked meadow-grass, white clover, alsike, red clover, and (where used) rye-grass.

The six plots were sown on June 7, 1886, the first two without a crop, the third in an oat crop. This third series, however, failed, and was replaced in 1888 by two other sets, both without rye-grass, to test whether a thick seeding of 16,000,000 seeds per acre or a thin one of 8,000,000 seeds per acre were the better. Half of each plot was to be cut for hay; this half was manured with 5 cwt. per acre decorticated cotton cake meal spread upon it. The other half of each plot was fed by sheep receiving the same amount of cotton cake.

The feeding and manuring were continued to 1893 (inclusive) and then stopped; in 1894 and 1895 all the plots were mown and the experiment terminated. The results for the hayed portions are given in Table 22.

TABLE 22.—PRODUCE OF HAY, TONS PER ACRE, GREAT HILL BOTTOM.

Plot.	Seeding and Cost per Acre.	Average for 3 years, 1886–88.	Average for 10 years, 1886–95.
1a	Without rye-grass .	2·97	2·10
1b	With rye-grass .	2·82	2·0
2a	Without rye-grass .	2·97	2·15
2b	With rye-grass .	3·10	2·0
3a	Thick seeding . .	1·5[1]	2·4[2]
3b	Thin seeding . .	1·0[1]	2·26[2]

The more costly seeding was no better than the simpler and cheaper one whether rye-grass was included or not.

[1] 1888 only. [2] 8 years only, 1888–95.

The thin seeding (without rye-grass) gave as good a return as the thicker seeding; and, taking the results as a whole, the cheapest seeding of all gave the best return.

An examination of the pastures at the close of the experiment showed that the fed plots were distinctly superior to those always mown. Tall fescue and cocksfoot were the prominent grasses, but they grew too strongly and the sheep could not keep them down. This was remedied after the experiment was over by feeding with cattle as well as with sheep, and the pastures benefited greatly thereby.

The experiments, however, failed to settle the rye-grass question. When the plots were examined at the end of 1890, rye-grass had invaded all those on which it had not been sown; it was impossible to say from their appearance which were the rye-grass plots and which not.

Since the experiment ceased, the field has been retained in grass, and rye-grass continues to thrive well over the entire area. There is nothing to justify de Laune's contention that rye-grass dies out after a year or two, leaving bare patches on which other grass will not grow.[1]

Experiments on Single Pasture Grasses.

Separate small plots of the different grasses were set out in Stackyard (light soil) and Warren Fields (heavy soil). The produce was weighed in 1887 and in 1888. Cocksfoot, tall fescue, meadow fescue, and timothy all gave higher yields than the different rye-grasses tried, and in the order given. Early cutting gave better results than late cutting, and losses occurred when the grass stood long enough to ripen so that seed formed. The produce was greater on the heavier than on the light soil, but the different grasses came out in the same order in both.[2]

[1] For details see *J. Roy. Agr. Soc.*, 1889, p. 30; 1891, p. 374; 1897, p. 643.

[2] *Ibid.*, 1889, pp. 25–9.

Permanence of Rye-grass.

In 1886 four kinds of rye-grass were sown in Stackyard Field : annual, Italian, perennial, and small-seeded rye-grass. They were hayed annually. None of them remained long true, and re-seeding had to be done in 1893. By 1898, however, they had become very impure, and the experiment was ended. The " annual " and " Italian " had practically disappeared, but the " perennial " and " small-seeded " varieties were more permanent.[1]

In another experiment Italian rye-grass over a period of three years gave larger yields of hay than either " Pacey's " or Dutch.[2]

Elliot's Grass Mixtures.

About the year 1900 considerable attention was directed to the " Clifton Park " system of laying down to grass poor, hard, and strong land, such as that on the Cheviot hill-sides, and using seed mixtures which comprised deep-rooting plants, such as chicory, burnet, kidney vetch, etc., that could strike down into the subsoil, and, in the words of the originator of the system, Mr. Robert H. Elliot, of Clifton Park, Kelso, act as " tillers " of the soil.

The method proved advantageous and resulted in markedly improved pastures of these hilly parts, so that it left its mark on the local agriculture. It has since been adopted elsewhere for the breaking up of heavy and stony land of poor quality, and as will be related later, ridding land of the troublesome " wild onion."

In the spring of 1901, 1½ acres of Great Hill Bottom were sown with one of Elliot's mixtures, the seeding being, per acre : cocksfoot, 6 lb. ; meadow fescue, 5 lb. ; tall fescue, 4 lb. ; hard fescue, 2 lb. ; smooth-stalked meadow-grass, 2 lb. ;

[1] For details see *J. Roy. Agr. Soc.*, 1899, p. 603.

[2] *Ibid.*, 1912, p. 311 ; 1913, pp. 406–7 ; 1914, pp. 301–2.

rough-stalked meadow-grass, ½ lb.; tall oat-grass, 3 lb.; golden oat-grass, ½ lb.; Italian rye-grass, 4 lb.; white clover, 2 lb.; alsike clover, 2 lb.; late-flowering red clover, 2 lb.; chicory, 2 lb.; burnet, 8 lb.; kidney vetch, 2½ lb.; sheep's parsley, 1 lb.; yarrow, 1 lb. Total, 47½ lb. Cost, £2 5s. 8d. per acre. The sowing was done under oats. The summer was dry and the seed failed: it was re-sown in September and a fair "take" was obtained which stood well through the winter. In spring, 1902, the crop grew quickly, chicory and burnet both being prominent, and on June 18, it was cut for hay; a second cut was taken August 18 26, the total yield of the two crops, as hay, being 3·35 tons per acre, which must be considered very satisfactory. The plots were grazed from this time on until 1908 when they were thrown into the rest of the field. Though they had the choice of the other herbage the cattle showed a decided preference for the Elliot's mixtures. The chicory was always eaten down; the sheep seemed to be very fond of it and in the end quite a nice pasture resulted.[1]

The experiment thus showed that Elliot's method would give a pasture. Its effect on the soil was not tested. In its complete form the grass is kept down for 4 or 5 years and then ploughed up; a root crop follows, then a corn crop, then another root crop, and afterwards corn in which the grass mixture is once more sown. The grass residues provide all the nitrogen and organic matter necessary, and the only manuring is a little superphosphate for the root crop.

Manuring of Grass Land.

Two series of experiments were made in Broad Mead. The first, commenced in 1893 and carried on to 1901, comprised a comparison of gypsum, basic slag, superphosphate, and lime. The plots were ¼ acre each and the manures were applied in 1893 and again in 1899. The plots, as a rule,

[1] For details see *J. Roy. Agr. Soc.*, 1903, p. 340; 1904, p. 301.

were alternately grazed and mown. In the 6 years in which a hay crop was taken (1894, 1896, 1897, 1899, 1901, 1903) the results are given in Table 23.

TABLE 23.—BROAD MEAD, HAY, TONS PER ACRE.

Plot.	Manure per Acre.	Average Produce Yearly.
1	Gypsum, 5 cwt.	1·35
2	Basic slag, 8 cwt.	1·4
3	Superphosphate, 3 cwt.	1·3
4	No manure	1·45
5	Lime, 2 tons	1·7

None of the manures except, perhaps, lime had produced any benefit. The second series was begun in 1901 and continued to 1926. Sulphate of potash was included and a farmyard manure plot was added.

The results of each weighing of hay, as also of the botanical separation, are set out in the *Journal* of the R.A.S.E. for the corresponding year ; the general averages for the entire period are given in Table 24.

The greatest yield was given by farmyard manure, but the herbage was coarser and less leguminous in character than on any other plot. The mineral manure while not increasing the yield increased the percentage of leguminous plants in the herbage.

Lime gave no increase of yield but produced the finest herbage and that most favoured by the animals.

While neither basic slag nor superphosphate alone had given any improvement in yield, the addition of sulphate of potash to either increased both the yield and the percentage of clover. The limed plot was conspicuous during the winter by its fresh appearance and the closer grazing which it had received. The application of superphosphate (3 cwt. per acre) and sulphate of potash (1 cwt. per acre) in 1910 and again in 1913 appeared to bring about a further improvement,

TABLE 24.—MANURIAL EXPERIMENTS ON GRASS LAND ALTERNATELY MOWN AND GRAZED, BROAD MEAD, 1901–26 (26 YEARS).

AVERAGE YIELD OF HAY AND BOTANICAL ANALYSIS.

Plot.	Manures per Acre.[1]	13 Years Average Weight of Hay per Acre, tons.[2]	Botanical Analysis.[3] Gramineæ, per cent.	Leguminosæ, per cent.	Others.
	Superphosphate, 5 cwt., and sulphate of potash, 1 cwt.	1·5	85		
	Basic slag, 10 cwt., and sulphate of potash, 1 cwt. .	1·65	88		
	No manure . . .	1·45	91		
	Lime, 2 tons [4] . . .	1·35	89		
	Farmyard manure, 12 tons	1·85	91		

but this was shown rather in the more ready feeding-off of the grass by stock than in the actual yield of hay.

One remarkable feature of the lime plot during the later years has been the spread of daisies, which is far greater than on any other plot. It is more marked in some years than in others, but at times the borders of the lime plot can be marked out by the presence or absence of daisies. No adequate explanation has yet been offered.[5]

Liming of Grass Land.

Two further sets of experiments on the liming of grass land were started in Broad Mead in 1910.

[1] The manures (except lime) were given in 1901, 1904, 1906, 1909, 1913, 1920, and 1924. Lime was given (alone) 1901, 1904, 1906, 1909, 1920, and 1925.

[2] The plots were hayed in 1903, 1905, 1907, 1908, 1910, 1913, 1915, 1916, 1917, 1918, 1919, 1920, 1921, and 1925. They were grazed in 1902, 1904, 1906, 1909, 1911, 1912, 1914, 1922, 1923, 1924, and 1926.

[3] Botanical examinations of herbage were made in 1903, 1905, 1907, 1908, 1910, 1915, and 1916.

[4] In addition to lime, Plot 4 had superphosphate, 3 cwt., and sulphate of potash, 1 cwt., per acre in 1910, 1913, and 1920.

[5] For details see *J. Roy. Agr. Soc.*, 1897, p. 646; 1901, p. 297; 1902, p. 325; 1904, p. 301; and subsequent yearly reports to 1926.

The following different varieties of lime were tried at the rate of 2 tons per acre :—

Plot 1.	Buxton lime.	Plot 4.	No lime.
,, 2.	Chalk lime.	,, 5.	Lias lime.
,, 3.	Magnesian lime.	,, 6.	Oolite lime.

The applications were repeated in February, 1916, and again in 1924. No other applications were given, and the land was, as a rule, mown and grazed in alternate years, and also grazed during the winter in the ordinary practice of the farm. The average yields of hay for the nine haying seasons [1] were, in tons per acre :—

Plot 1.	Plot 2.	Plot 3.	Plot 4 (No lime).	Plot 5.	Plot 6.
1·35	1·25	1·35	1·25	1·3	1·3

The plots receiving Buxton lime and the chalk lime looked the best, and the magnesian lime plot was distinctly inferior. Between lias lime and oolite lime there was nothing to choose.

The experiment showed, however, that while lime improved the grazing, it could not by itself materially increase the vigour of the herbage or produce larger crops of hay.

In 1913 five more plots, each ¼ acre in size, were laid out in Broad Mead as follows : 1, Lump lime ; 2, Ground lime ; 3, No lime ; 4, Ground limestone ; 5, Ground chalk.

Instead, however, of applying the same weight of lime to each, the applications were made on a cost basis, 20s. per acre, independent of cost of carriage, cartage, etc., being expended on each plot. The dressings were given in 1913 and again in 1920. The average yields of hay over the 8 hayed years [2] were in tons per acre :—

Plot 1.	Plot 2.	Plot 3 (No lime).	Plot 4.	Plot 5.
1·5	1·45	1·35	1·55	1·6

[1] The plots were hayed in 1913, 1915, 1916, 1917, 1918, 1919, 1920, 1921, 1925, and grazed in 1911, 1912, 1914, 1922, 1923, 1924, and 1926.

[2] The plots were hayed in 1913, 1915, 1916, 1917, 1918, 1919, 1920, and 1921, and grazed in 1914, 1922, 1923, 1924.

The advantage of applying lime was again brought out, and ground chalk and ground limestone proved to be as good as any of the forms used.[1]

Comparison of Mowing and Grazing.

This experiment was made on "Westbrook Field," a permanent grass field the soil of which was much heavier than usual on the farm.

The field was divided into three equal parts. One was mown every year, a second was grazed only, and the third was alternately mown and grazed. The yields were, in tons per acre :—

Produce of Hay, Tons per Acre, on Divisions when Mown.

	1915.	1916.	1917.	1918.	1919.	1920.	1921.	Average.
1. Always mown . .	1·4	2·35	1·25	2·05	1·55	1·2	0·7	1·5
2. Mown in alternate years . . .	1·5	—	1·3	—	1·5	—	0·7	1·25

In respect of hay-yield the portion always mown had an advantage, but the hay produced under the alternate treatment contained more clover, and it also left a better bottom.

The portion that had been fed every year, however, had much the nicest sward, containing far more clover than the other portions ; it was always closely grazed and evidently was the one most relished by stock.[2]

Clovers.

In 1883 small single plots were set up under the direction of W. Carruthers, Botanist to the Society, to test the longevity of several varieties of clover. The results showed that the perennial red clover disappeared in 3 years, that Dutch white clover was likewise of short duration, but that alsike,

[1] For details see *J. Roy. Agr. Soc.* Reports of Woburn Farm for the several years concerned (1910–26).

[2] *Ibid.*, 1915, p. 343 ; 1918, p. 276 ; 1923, p. 130.

cowgrass (both of which yielded well), and English white clover were somewhat more permanent.[1] The dying-off of the clovers was attributed to "clover sickness." Miss Ormerod, then consulting Entomologist to the Society, put this down to an eel-worm (*Tylenchus devastatrix*), which she found in the dying plants. Their mere presence in the plants is, however, no proof of their being the cause of the disease. Carruthers, on the other hand, attributed it to a fungus which spread in circles, thus causing the increasing blanks so frequently noticed in a dying clover crop. The problem of "clover sickness" is not yet completely solved.

The produce of the plots cut at flowering was considerably greater than that cut at seeding time, and the earlier cut plants appeared the more vigorous. This suggests that the life of clovers is longer in permanent pasture than when cut for hay.

Neither sulphate of ammonia or nitrate of soda used alone had any effect on yield. Phosphates raised the produce somewhat, and sulphate of potash, either by itself or in combination with phosphatic and nitrogenous dressings, was beneficial; it did not, however, prolong the life of the clovers.[2]

After the clovers had failed in 1899 other leguminous plants were sown so as to ascertain whether land on which one kind of clover had failed would then carry a different kind. These, however, failed with the single exception of lucerne, which grew very well on land where red clover had previously failed; it continued to thrive for 7 or 8 years afterwards (p. 74).

Varieties of Clover.

Trials made on small single plots during the seasons 1900 to 1906 showed that *Trifolium incarnatum*, both the red and

[1] *J. Roy. Agr. Soc.*, 1886, pp. 252–9.
[2] For details see *ibid.*, 1886, pp. 252–9, and 1897, pp. 646–7.

the white variety, was a useful crop in that it could be broadcasted immediately after a corn crop with no more preliminary cultivation than scarifying and harrowing, and it gave a considerable quantity of green material which could all be removed in time for a crop of mustard or white turnips.

Of the Canadian and American and other varieties of red clover tested, none was superior to the English sorts.

The wild white clover trials began in 1912, as the result of the considerable interest which had for some years preceding been taken in this crop in the north of England largely through the experiments of D. A. Gilchrist at Cockle Park, Northumberland. A grass mixture containing wild white clover gave no better yield than one containing the ordinary white variety, but the wild lasted longer than the ordinary variety and each year showed up better in the aftermath besides leaving the soil richer in nitrogen.[1]

Lucerne.[2]

Lucerne, drilled in 1889 on land where red clover had previously failed, established itself successfully, and continued to flourish until 1896, and less well until 1901, without being resown. This helped to disprove a belief, then general, that lucerne would grow only on a chalk soil. The crop was cut three and sometimes four times a year.

Until 1896 manurial treatments apparently had little effect except that the plot receiving only sulphate of ammonia gave the lowest yield, while that receiving sulphate of ammonia with potash and phosphate gave the highest. After 7 years of constant cutting a more marked manurial

[1] For details see: *Trifolium, J. Roy. Agr. Soc.*, 1902, p. 329, and 1905, p. 202. *Canadian and American varieties, ibid.*, 1904, pp. 300–1; 1906, pp. 309–10. *Wild white clover, ibid.*, 1913, pp. 404–5; 1914, pp. 300–1; 1915, pp. 337–8; 1916, pp. 247–8.

[2] For details see *J. Roy. Agr. Soc.*, 1897, pp. 652–3; 1899, pp. 603–4; 1901, pp. 294–6; 1902, pp. 324–5; 1904, p. 299; 1905, p. 200; 1906, pp. 308–9; 1907, pp. 258–9.

response was shown; the unmanured plot declined, as did also those with nitrogen only and phosphates only. The "potash only" plot showed for a time a relative superiority, but the complete manures (phosphates, potash, and nitrogen) alone maintained their yields. It was deduced that lucerne did not until the ninth or tenth year require more potash than the soil could supply, but after that time the lack of potash showed itself.

In the spring of 1902 the plots were dug up, soil samples were taken, and lucerne seed drilled again.

In 1903 the light colour of the crop on the "potash only" plot seemed to indicate the need of some nitrogenous manuring as well. A similar chlorotic appearance was recorded in 1904. The only manurial responses were to complete manure, and as before the result was the same whether the nitrogen was supplied by nitrate of soda or sulphate of ammonia.[1]

Varieties of Lucerne.

Trials were made in 1905 and in 1911 on single plots of several different varieties of lucerne: of these, one from Russia seemed somewhat superior to the ordinary Provence variety, while one from Turkestan was decidedly poor.[2]

The 1911 plots were divided, one half being sown under barley and the other half with no cover crop. No differences in yield were obtained over the 4 years of the trial.

Sainfoin (*Onobrychis sativa*).

This was sown in 1900 and left for 5 years till 1904, by which time the crop had become very weedy and the yields

[1] For details see *J. Roy. Agr. Soc.*, 1897, p. 652; 1899, p. 603; 1901, p. 294; 1902, p. 324; 1904, p. 299; 1905, p. 200; 1906, p. 308; 1907, p. 258.

[2] *Ibid.*, 1908, pp. 350–1; 1909, pp. 376–7; 1910, pp. 353–4; and each succeeding year to 1916.

only small. The average green weights over the 5 years were, in tons per acre :—

	English.	French.
Giant . . .	4·85	2·28
Common . . .	4·95	3·5

This compared with yields for lucerne of 16 to 18 tons of green matter, so that there was obviously no advantage in growing sainfoin.[1]

Soya Bean (*Soya hispida*) and Gram (*Cicer arietinum*).

Both these were sown in 1912; they grew, but produced no pods. It was concluded that the seed would not mature in this country.

Lathyrus sylvestris.

This was grown from 1888 to 1901, and the yield of green crop varied from 4 to 14 tons per acre. It stood for 10 years. It was, however, practically useless as fodder, for no kind of stock would take to it.[2]

Gorse.

In May, 1897, "French Gorse" was drilled in a barley crop in rows 18 inches apart. No manure was given. It grew well and stood the winter: in October, 1898, it yielded 11 tons green produce per acre. Unfortunately it could not easily be fed to stock: it had to be put through a cake breaker and bruised with a wooden mallet, a tedious and troublesome business; further, it had to be fed green.[3]

[1] See *J. Roy. Agr. Soc.*, 1901, p. 296; 1902, p. 324; 1904, p. 299; and 1905, p. 201.

[2] See *ibid.*, 1891, p. 377; 1897, p. 654; 1899, p. 604; 1901, p. 296, and 1902, p. 325.

[3] See *ibid.*, 1899, pp. 367–73.

Non-leguminous Fodder Crops.

Maize yielded 20 tons per acre green fodder in 1894 and 17 tons per acre in 1897.[1]

Kohl-rabi was grown in 1900 and 1901 and although it suffered at first from wood pigeons, it yielded well in the end.[2]

[1] *J. Roy. Agr. Soc.*, 1897, p. 654.
[2] See *ibid.*, 1902, p. 329.

CHAPTER VII.

VARIOUS ENQUIRIES.

Sugar-beet.

FROM 1910 to 1915 various trials were made to see how yields of sugar-beet would compare with those of mangolds grown on adjoining plots and receiving the same manure. The results may be summarised as follows :—

Year.	Field.	Yield, Tons per Acre. Mangolds.	Yield, Tons per Acre. Sugar beet, weight.		Sugar, per cent in Beet.
1910	Warren (heavy) .	31·55	12·1	unwashed	14·53
	Stackyard (light)	—	7·5	washed	15·8
	Road piece (heavy)	44·2	22·5	unwashed	
1912	Warren . .	24·05	13·0	washed	7·57

The yield of mangolds was thus about double that of sugar-beet.[1]

An estimate was made of the cost of growing and lifting the two crops, and it appeared that sugar-beet cost about £2 per acre more to grow and to lift than did mangolds.[2]

Linseed.

After preliminary attempts in 1912 and 1913, four varieties were grown in 1914 with the following results :—

[1] The extra weight, however, is mostly water. When the comparison is made on the basis of dry matter, the difference becomes very small.—E.J.R.

[2] For details see *J. Roy. Agr. Soc.*, 1910, p. 338 ; 1911, p. 399 ; 1912, p. 312, and 1915, p. 339.

Variety.	Date of Cutting.	Weight.	Per Acre, bushels.	Straw, cwt.	Oil in Seed.
"La Plata" . .	Sept. 4	1099	19·9	15·75	39·5
"Morocco" . .	Sept. 4	837	15·1	17·25	37·9
"Steppe" . .	Aug. 27	1129	20·3	14·0	38·9
White-flowering (Dutch)	Sept. 1	670	12·2	20·75	34·1

The "La Plata" and "Morocco" were the best. The Dutch seemed more suited for fibre than for oil.

As it has been maintained that linseed is a very exhausting crop for the land, wheat was grown after the linseed, and, compared with wheat after oats grown in adjoining land, the wheat after the linseed yielded considerably better than that after oats.[1]

Finger-and-toe in Turnips.

The Woburn soil being deficient in lime is very subject to "finger-and-toe" (*Plasmodiophora brassicæ*), and experiments on this disease were made from 1896 to 1904.

The results confirmed the fact already known that a dressing of lime at the rate of about 2 tons per acre mitigated

TABLE 25.—EFFECT OF VARIOUS TREATMENTS ON INCIDENCE OF FINGER-AND-TOE IN TURNIPS.[2]

Applications per Acre.	Sound Roots, tons.	Usable Roots, cwt.	Unsound Roots, cwt.	Total Weight of Roots per tons acre.
Lime, 2 tons . .	6·45	13·5	6·5	7·5
Nothing	none	1·0	6·0	0·35
Gas lime, 2 tons . .	2·25	34·5	28·5	5·4
Basic slag, 10 cwt. .	0·15	9·5	16·0	1·45
Nothing . . .	none	0·5	6·0	0·3
Finely divided lime, 2 tons . . .	3·65	17·5	11·0	5·1
Carbolised lime, 2 tons	4·25	15·5	10·75	5·6

[1] For details see *J. Roy. Agr. Soc.*, 1912, p. 311; 1913, p. 407; 1914, p. 303; 1915, p. 334.

[2] *Ibid.*, 1897, p. 650; 1901, p. 298; 1903, p. 345; 1904, pp. 304, 305; 1905, pp. 204, 205.

the harm done and increased the yield. Neither gas lime nor carbolised lime was as good as ordinary lime, and neither borax, copper sulphate, nor kainit was effective. The results of 1902 were typical, and are given in Table 25.

Spraying for Potato Disease.

Between 1892 and 1911 various demonstrations of the effects of spraying potatoes as a protection against *Phytophthora infestans* were made.

These showed that even when there was no obvious disease, spraying increased the yield by keeping the plants growing longer than otherwise they would do. The addition of molasses to the spray, which had been proposed for the purpose of improving its adhesive power, was no advantage.

The 1902 results are typical, and are given in Table 26.

TABLE 26.—EFFECT OF SPRAYING ON *PHYTOPHTHORA INFESTANS*.

Variety.	Treatment.	Saleable, tons.	Seed, cwt.	Pig, cwt.	Diseased, cwt.	Total, tons.
"British Queen"	Not sprayed	3·6	15·75	7·0	4·0	4·9
	Sprayed .	3·65	14·75	8·75	1·0	4·9
"Challenge"	Not sprayed	1·95	12·5	6·5	17·25	3·8
	Sprayed .	2·75	17·5	10·75	1·5	4·25
"Selected Giant"	Not sprayed	3·05	14·75	6·25	4·25	4·35
	Sprayed .	5·0	19·5	6·25	1·5	6·4
"Up-to-date"	Not sprayed	4·35	13·0	5·0	3·5	5·4
	Sprayed .	6·6	13·5	3·5	1·25	7·5

For details see *J. Roy. Agr. Soc.*, 1892, pp. 771–83; 1897, p. 649; 1901, p. 298; 1902, p. 327; 1903, p. 343; 1904, p. 303; 1909, p. 380; 1911, p. 403.

CHAPTER VIII.

FEEDING EXPERIMENTS.

BULLOCK-FEEDING EXPERIMENTS.

I. Linseed Cake *v.* Decorticated Cotton Cake and Maize-meal.

THE first of the Woburn experiments on the fattening of bullocks was carried out with Hereford bullocks in the three seasons 1878 to 1881. Linseed cake had been long recognised as a valuable fattening material, but decorticated cotton cake had only recently come into use, and feeders were somewhat uncertain about it. The decorticated cotton cake of those early days was, however, somewhat different from that obtainable now; it was nice and soft, well-decorticated, containing 15 to 16 per cent of oil and 40 per cent of albuminoids, against the 8 or 9 per cent of oil common now, the modern samples being frequently very hard pressed and not thoroughly decorticated.

In the first trial, which commenced on November 9, 1878, and continued until January 17, 1879, four Hereford bullocks, rising 3 years old, were fed on linseed cake along with roots and chaff; four others, selected as being of nearly the same weight and character as the other lot, received decorticated cotton cake and maize-meal in equal amounts, and roots and chaff like the first. The animals were not tied down to eat any particular quantity of each food, but were given those amounts which they took readily and cleaned up well. The analyses of the foods were:—

	Decorticated Cotton Cake.	Linseed Cake.	Maize-meal.
Oil . . .	14·9	9·9	1·8
Albuminoids .	43·1	29·9	8·6

In the course of the experiments the four bullocks ate 34 cwt. of linseed cake as against 19 cwt. of decorticated cotton cake and 19 cwt. of maize-meal consumed by the other four.

The experiment ended and the bullocks were weighed on January 17, 1879. The experiment was repeated in 1880 and again in 1881. The results are given in Table 27.

TABLE 27.—COMPARISON OF LINSEED CAKE WITH DECORTICATED COTTON CAKE AND MAIZE-MEAL AS FOOD FOR CATTLE.

Cake Supplied.	Winter of	No. of Bullocks.	Days.	Cwt. of Cake or Corn Consumed. (*a*)	Live-weight Increase lb.	Average Gain per Head daily, lb.	Cost of Purchased Food per lb. Increase in Live-weight.
Linseed	1878–79	4	70	34	633	2·26	6¼d.
	1879–80	3	63	26	401	2·12	8¾d.
	1880–81	3	63	29	313	1·7	11⅛d.
Decorticated cotton cake and maize-meal	1878–79	4	70	19, 19	640		5⅛d.
	1879–80	3	63	13, 13	401	2·08	5⅛d.
	1880–81	3	63	16, 16	407	2·6	6¼d.

(*a*) In addition to—
1878–9, 17 cwt. wheat-chaff; 10 cwt. white turnips; 88 cwt. swedes.
1879–80, 9 cwt. hay-chaff; 4½ cwt. wheat-chaff; 34 cwt. sliced mangolds.
1880–81, 10½ cwt. hay and hay-chaff; 63 cwt. mangolds.

Decorticated cotton cake and maize-meal produced a greater gain in live-weight and at lower cost than the same weight of linseed cake.[1]

II. Decorticated Cotton Cake *v.* Undecorticated Cotton Cake.

Decorticated cotton cake was then tested against undecorticated cake for fattening bullocks.

[1] The prices were for the first 3 years respectively: Linseed cake, £9 10s., £11 5s., £10 10s.; Decorticated cotton cake, £7 15s., £8 7s. 6d., £8 7s. 6d.; Maize-meal, £6 17s. 6d., £7 15s., £7 15s. per ton respectively.
For further details see *J. Roy. Agr. Soc.*, 1880, p. 149; 1881, p. 654.

This experiment was made in the seasons 1888–9 and 1890–1 with bullocks rising 3 years old; four Herefords in the first test and nine Shorthorns in the second. The basal ration consisted of linseed cake, gritled barley, roots, and hay. The first experiment lasted for 145 days—December 20, 1888, to May 14, 1889, and the average daily feeding was 3·3 lb. per head of either cotton cake with 2·88 lb. of linseed cake and 4 lb. of barley.[b] The second experiment was also with Shorthorn bullocks fed much the same as before, and lasted 127 days.

TABLE 28.—COMPARISON OF DECORTICATED AND UNDECORTICATED CAKE AS FOOD FOR CATTLE, 145 DAYS IN 1888–89, AND 127 DAYS IN 1890–91.

Cake Supplied.	Winter of	No. of Bullocks.	Live-weight Increase, lb.	Average Gain per Head daily, lb.	Carcass-weight, cwt.	Prices per Head Realised. £ s. d.
Decorticated cake	1888–89	4	1232	2·21		
	1890–91	8	2352	2·38	7·3	22 4 8
Undecorticated cake	1888–89	4	1146	1·97		
	1890–91	9	2057	1·84	6·9	20 16 0

(*b*) In addition to—
1888–89, 46 cwt. hay-chaff; 10 tons roots.
1890–91, 16 lb. hay-chaff; 40 lb. roots per head per day.

The analyses and prices per ton delivered were :—

	Decorticated Cotton Cake. 1st Expt.	Decorticated Cotton Cake. 2nd Expt.	Undecorticated. 1st Expt.	Undecorticated. 2nd Expt.
Oil . .	14·8	12·4	4·6	5·2
Albuminoids	44·3	45·8	24·2	22·3
Price per ton	£6 9s. 2d.	£6 18s. 6d.	£6 2s. 6d.	£5 5s. 0d.

The decorticated cotton cake gave the better result, and this would presumably be enhanced if the residual manurial values were taken into account.[1]

[1] For further details see *J. Roy. Agr. Soc.*, 1891, p. 585.

6 *

III. Heavy *v.* Light Feeding of Cake. Can Hay Economically Replace Cake?

Sixteen Shorthorn bullocks were used; six received 3 lb. per head daily of decorticated cotton cake and 3 lb. of linseed cake together with roots and hay; six received the same cakes but only 1½ lb. of each, along with hay and roots; four received no cake but only hay and roots. The hay and roots were in each instance given *ad libitum*, but the quantities were noted.

Lot 1 had its ration of cake gradually increased from 6 lb. per head daily to a maximum of 10 lb. per head daily. Lot 2 worked up to a maximum of 5 lb. per head daily. One of the "hay" bullocks developed inflammation of the lungs as the experiment proceeded and had to be taken out. The feeding began on December 30, 1889, and was continued until April 19, 1890—a period of 110 days. The average gains per head and the foods consumed by each lot daily are given in Table 29.

TABLE 29.—REPLACEMENT OF CAKE BY HAY. COMPARATIVE EFFECTS OF HEAVY AND LIGHT CAKE FEEDING.

110 Days.	Lot 1. Heavy Cake Feeding.	Lot 2. Light Cake Feeding.	Lot 3. Hay replacing Cake.
Gain per head daily, lb.	3·12	2·54	1·30
Food consumed per head daily:—			
Cake (linseed cake and decorticated cotton cake in equal amounts)	8·67	4·33	
Hay	13·73	15·40	17·03
Roots	40·18	44·27	48·44

The carcass-weights, at 4s. 7d. per stone, were the basis of sale. Only the bullocks receiving high cake feeding sold at a price sufficient to cover the cost of the food. The low cake feeding showed a small loss, while the feeding with hay alone was considerably the least economical. It appears then that low-feeding of cake as against fairly high-feeding

is not economical, and that hay cannot profitably replace cake.[1]

IV. 1891-2. Earth-nut Cake as a Food for Cattle.

Earth-nut or ground-nut cake, now a well-known food for stock, and a common ingredient of compound cakes and meals, was, in 1891, quite new to this country, although it had been in use on the Continent and in India where earth-nut is largely grown. In the winter of 1891–2, a comparison was made between earth-nut cake and bean-meal, the other foods used being oats, barley, roots, and clover-hay.

The analyses were :—

	Earth-nut Cake.	Bean-meal.
Oil	8·4	2·01
Albuminoids	47·44	23·25
Carbohydrates	22·27	46·55
Price per ton	£8 4s. 0d.	£8 17s. 6d.

Four Hereford bullocks were put on each ration. Two lb. per head daily of the cake or meal were given at first; this was gradually increased to 4 lb. per head daily. The animals took to the new food quite well and apparently did satisfactorily.

The experiment lasted from November 28, 1891, until March 14, 1892, a period of 107 days. The live-weight gains and prices realised were :—

107 Days.	Gain per Head daily Live-weight, lb.	Prices Realised per Head.[2]	Cost per Head of Additional Food.
Earth-nut feeding	2·2	£23 6s. 3d.	£3 4s. 0d.
Bean-meal feeding	2·0	£23 7s. 8d.	£3 6s. 9d.

It was concluded that earth-nut is probably rather a better food than bean-meal; a result which has since been abundantly confirmed by practical experience.[3]

[1] For details see *J. Roy. Agr. Soc.*, 1890, pp. 399–407.

[2] 4s. 8d. per butcher's stone of 8 lb.: i.e. 7d. per lb. dead-weight.

[3] For details see *J. Roy. Agr. Soc.*, 1892, pp. 727–30.

V. Home-grown *v.* Purchased Foods.

1887–8.—For some time prices of home-grown corn had been falling, and an experiment was set up to see how home-grown produce compared with purchased cake or meal as food for bullocks. The foods compared were :—

(*a*) Home-grown beans, oats, barley, wheat.
(*b*) Purchased linseed cake, decorticated cotton cake, maize-meal.

The respective prices were, per ton : Linseed cake, £8 ; Decorticated cake, £6 10s. ; Maize-meal, £6 1s. ; Beans, £8 ; Barley, £6 5s. ; Wheat, £6 16s. ; Oats, £6 17s.

Oats and barley were given crushed, the wheat gritled.

The daily feeding was (*a*) purchased food : 3 lb. each of linseed cake, decorticated cotton cake, and maize-meal per head ; (*b*) home-grown food : 3 lb. each of beans, oats, and barley per head ; (*c*) 3 lb. each of wheat, oats, and barley per head, with roots and hay in each case.

Six Hereford bullocks were used in each of two of the sets and four in the third ; the experiment lasted from December 19, 1887, to April 9, 1888, a period of 112 days. The quantities of the various foods were altered as found necessary, but all weights of food and of water consumed were recorded.

Over the 112 days 9 lb. of cake or meal and 40 lb. roots were taken daily per head, and all three sets consumed much the same weight of hay and straw chaff, but the cake-fed animals took 43 lb. of water daily as against 36 lb. with beans, oats, and barley, and 28½ lb. with wheat, oats, and barley. Further, the cake-fed bullocks ate up their food quickly and then lay down, while the corn-fed lots generally made two feeds of their supply, lying down between times.

The results were :—

112 Days.	Linseed Cake, Decorticated Cotton Cake and Maize-meal.	Beans, Oats, and Barley.	Wheat, Oats, and Barley.
Gain per head daily, lb.	2·65	2·35	2·15
Cost per lb. in live-weight increase	2·62	3·17	3·2
Albuminoid ratio of mixed diet	1 : 4·8	1 : 6·33	1 : 7·65

1891–2.—The second experiment, carried out in 1891–2, was simpler ; the cake was linseed cake only, while the home-grown food was beans, oats, and barley, the basal ration being roots and hay-chaff. The prices per ton were : linseed cake, £9 16s. ; beans, £8 18s. ; oats, £8 6s. ; barley, £6 8s. Twelve Hereford bullocks were used, and the experiment lasted from November 28, 1891, to March 14, 1892, a period of 107 days.

The bullocks received 6 lb. per head daily of the cake or meal and this was gradually increased to 12 lb. per head, the average consumed daily over the whole period being 8·18 lb. Both sets consumed approximately the same quantities of roots, hay and water.

The results are given in Table 30.

TABLE 30.—COMPARISON OF HOME-GROWN AND PURCHASED FOODS.

107 Days.	Linseed Cake.	Beans, Oats, Barley.
Gain in live-weight per head daily, lb.	2·03	2·01
Average price per head [1] (7d. per lb. dead-weight)	£23 12s. 6d.	£23 7s. 8d.
Cost per head of special foods used during 107 days	£3 17s. 10d.	£3 6s. 9d.

In the first experiment the purchased foods gave the better results, but in the second experiment the home-grown foods were financially the better though the live-weight increase was practically the same for both cake and meal, but less than when a mixture of cakes had been given. Further,

[1] 4s. 8d. per stone dead-weight, 1 butcher's stone being 8 lb.

the linseed cake had at a later period risen 36s. per ton while the beans and oats had fallen in price.[1]

1894–5.—The experiment was repeated in a somewhat different form in the winter season 1894–5. The changes consisted in using a mixture of linseed and decorticated cotton cake and in not replacing cake entirely by corn, but in giving a limited amount of cake and making up with wheat and barley in addition to roots and hay. Twelve Hereford bullocks were used and divided into two sets.

As in the first experiment, the cake-fed bullocks took their supply at once, the cake-and-corn lot taking theirs in two feeds: also the cake-fed bullocks drank much more water than the others, the relative amounts being 40 lb. and 25 lb. per head daily; both sets, however, consumed approximately the same weight of roots and hay. The results after 112 days' feeding were:—

112 Days.	Live-weight Gains per Head daily, lb.	Average Carcass-weight, stones.	Price Realised per Head.	Cost of Food per Head.
Cake-fed lot .	1·7	89·25	£10 6s. 8d.	£4 1s. 3d.
Cake-and-corn fed lot	1·8	90·25	£10 13s. 4d.	£3 12s. 2d.

The live-weight gains were the same on both rations, but the home-grown foods were again the cheaper.[2]

1901–2.—A fourth experiment was made in 1901–2 on somewhat different lines. Sixteen blue-grey bullocks were used and divided into two lots. After 106 days' feeding the results were:—

106 Days.	Gains in Live weight per Head daily, lb.	Cost of Food per Head.	Average Carcass, cwt.
Linseed and decorticated cotton cake, maize-meal	2·18	£5 2s. 0d.	
Home-grown beans, oats, and wheat	1·72	£5 0s. 0d.	

[1] For details see *J. Roy. Agr. Soc.*, 1888, pp. 481–6; 1892, pp. 723–7.
[2] *Ibid.*, 1896, pp. 41–53.

The meat of the cake-fed animals showed excessive fat and the butcher preferred the others.[1]

Two of the trials had gone one way and two the other. Such things necessarily happen where the comparison is based on shifting prices. The live-weight increases, however, had also varied.

VI. Can Roots be Dispensed With in the Feeding of Bullocks?

1893–4.—The severe drought of 1893 caused the hay and root crops to be very short, and many suggestions were put forward as to the best way of feeding during the coming winter. A mixture of straw-chaff with linseed oil was widely recommended. This was tested during the winter of 1893–4.

Four Hereford bullocks receiving 7 lb. per head daily of mixed decorticated cotton cake and barley, with barley-straw and chaff and roots *ad libitum*, were compared with four having the same cake and corn ration but with barley-straw chaff mixed with linseed oil [2] in place of roots.

Three-fourths of a pint of oil per head was at first fed daily, but this produced "looseness" in the animals, and the quantity was reduced to half a pint per head. However, the animals still did not thrive, in spite of their cake and barley.

After 61 days the experiment was stopped; the results were:—

	With Roots, etc.	Without Roots.
Gain per head daily, lb. . .	2·07	0·29

The "roots" lot consumed on the average 41 lb. of roots and 8·55 lb. of barley-straw chaff per head daily, as against a daily average of 7·71 lb. of chaff and ·62 pint of linseed oil. Cake, corn, and long-straw were the same in both sets, but

[1] For details see *J. Roy. Agr. Soc.*, 1902, pp. 330–8.

[2] One quart of oil was mixed with one gallon of boiling water and sprinkled over the chaff.

the "no roots" bullocks drank practically double the amount of water.

It was next decided to try giving two of the oil-fed bullocks the same amount of linseed oil as before, but in the form of linseed cake. The other two were given roots.

The results were :—

	Food Consumed per Head daily.			
	Gain per Head daily, lb.	Roots.	Barley-chaff.	Linseed Cake.
Bullocks fed with roots throughout (45 days) . . .	1·85	44·0	8·2	
Bullocks previously fed with linseed oil and no roots, but now put on roots (80 days) . .	1·80	45·7	8·0	
Bullocks previously fed with linseed oil and no roots, but now put on linseed cake, though without roots (80 days) .	1·28		11·6	5

In each case cake and corn were kept to a total of 10 lb. per head daily, the 5 lb. of linseed cake in the third lot being included in the total and supplying just the same amount of linseed oil as these bullocks had previously been receiving in the form of linseed oil.

The bullocks fed throughout on roots continued to gain steadily during the further period. The substitution of roots for linseed oil gave a practically equal gain, although the bullocks had done so badly before; while the substitution of linseed cake for linseed oil induced a marked change in the earlier result, although roots were still withheld. The result, however, was not as good as when roots were given.[1]

VII. Economy in the Feeding of Roots.

An experiment was made in 1895–6 to see how far roots could be economised, and a succession of dry seasons with

[1] For details see *J. Roy. Agr. Soc.*, 1895, pp. 102–7.

consequent difficulty in securing good root crops gave some importance to the trial.

The Woburn farm experience had shown that 40 lb. to 50 lb. per head daily was about the amount which bullocks rising 3 years would ordinarily take when given cake, corn, hay, and straw-chaff. Sixteen Hereford bullocks were therefore divided into two lots, one receiving 40 rising to 50 lb. per head daily of roots, the other only 25 rising to 35 lb. Both had in addition linseed cake, decorticated cotton cake, and barley (6 lb. rising to 10 lb. per head daily) with hay and oat-straw chaff.

The results after 112 days' feeding are given in Table 31.

TABLE 31.—COMPARISON OF LIGHT AND HEAVY FEEDING WITH ROOTS.

Gain per Head, lb. per day.	1st Period.	2nd Period.	3rd Period.	4th Period.
Light-feeding with roots	1·75	2·05	1·35	1·66
Heavy-feeding with roots	1·97	2·32	1·25	1·75

The bullocks were sold by dead-weight at 4s. per stone. The heavy-feeding returned 2s. 11d. more per head than the light-feeding, but at an additional cost of 3s. 10d. per head in food. Taking into account the greater manurial value of the heavy-feeding, there was little to be said one way or the other.[1]

The experiment was repeated in 1896–7 with Shorthorn bullocks.

The results were :—

	Gain in Live-weight. lb. per Head daily.
Light-feeding with roots	1·82
Heavy-feeding with roots	2·05

The bullocks receiving the heavy root ration sold (dead-weight basis) for 1s. 4½d. per head more than those with the lighter ration. As the cost of the food of the light-fed lot was more than that of the other, owing to the longer period

[1] For details see *J. Roy. Agr. Soc.*, 1896, pp. 560–7.

required before the animals were ready for the butcher, the gain for the heavy-feeding was 6s. 1d. per head.[1]

The advantage thus lies generally with the heavy-feeding (40–50 lb. per head daily) of roots, yet, when roots are scarce, the amount may be reduced without fear of heavy loss.

VIII. Early Feeding of Mangolds to Bullocks.

1898–9.—It is often considered inadvisable to feed mangolds to stock before the spring: if fed before Christmas, they are apt to cause "scouring." Undecorticated cotton cake, bean-meal, and long-hay in plentiful amount have each been suggested as likely to stop the "scouring"; an experiment was made to see how far this was so.

Three lots of four Shorthorn bullocks, rising 3 years, were fed on a basal ration of 4 lb. linseed cake, meadow-hay chaff, oat-straw chaff, with 3 lb. long-hay per head daily; in addition, lot 1 had 2 lb. undecorticated cotton cake, lot 2, 2 lb. bean-meal, and lot 3, a further 2 lb. long-hay and 2 lb. linseed cake each per head daily.

All received mangolds from December 2 onwards: at first 28 lb. per head daily, then, as there was no sign of "scouring," 35 lb. per head daily. Almost at once, however, "scouring" began, and with each lot equally. The additional foods were increased, and oat-straw chaff replaced by hay-chaff, as the bullocks were inclined to reject the oat-straw. With these changes it was found possible to increase the roots, first to 35 lb. and then (January 1, 1899) to 40 lb. per head daily. With the higher amount, the bullocks receiving cotton cake or bean-meal were slightly affected at first, and speedily recovered; but all four animals receiving long-hay only were distinctly affected, and the mangold ration had to be reduced to 35 lb. per head daily. After this they recovered, but they had experienced an evident

[1] For details see *J. Roy. Agr. Soc.*, 1898, pp. 172–82.

"set-back." By January 21 the animals receiving the cake or bean-meal were able to take 45 lb. per head of mangolds daily.

The bullocks were then weighed and showed quite fair gains, except in the case of lot 3 (long-hay). Bean-meal gave the highest gain (1·9 lb. per head daily), that with cotton cake being 1·6 lb.

As long-hay had proved a failure in stopping the "scouring," these animals were given 4 lb. of decorticated cotton cake and 4 lb. of linseed cake per head daily, and they at once markedly improved. The others were given additional cake and could now receive up to 50 lb. per head of mangolds daily, but this was about the limit to which they would go. The bean-meal continued to show rather the better return throughout, but, with the altered feeding, all did quite well and took the 50 lb. of mangolds per head daily without recurrence of any trouble.

It was concluded that mangolds could be fed to fattening bullocks quite well as early as December, provided that at first the quantity given be limited to 28 or 30 lb. per head daily, and that, with the other foods, there be given 2 lb. or so of either undecorticated cotton cake or bean-meal. From January onwards the ration of mangolds could be gradually increased to 50 lb. without scouring.[1] Long-hay was not effective (in stopping scouring).

IX. Dried Grains as a Substitute for Hay.

1897–8.—Dried grains being at the time rather in favour as a food for bullocks, the question arose how far they could be used in substitution of hay. They cost £3 15s. per ton, which, with carriage and carting, brought the total cost to £4 8s. 3d. per ton delivered; while good hay might be put at £3 per ton or, with cost of carriage and carting, £3 5s. per ton.

[1] For details see *J. Roy. Agr. Soc.*, 1899, p. 559.

The hay used had been grown on the farm and was good and well made.

Sixteen Shorthorn bullocks were divided into two lots of 8; each received linseed cake, decorticated cotton cake, maize-meal, and roots; in addition one set had dried grains, the other had hay, both *ad libitum*. The analyses and costs were :—

	Dried Grains.	Hay.
Albuminoids . .	17	7·5
Fibre . . .	16·8	24·0
Carbohydrates .	42–45	42–45
Price per ton .	£3 15s. 0d.	£3 0s. 0d.
Plus cartage: total	£4 8s. 3d.	£3 5s. 0d.

During the 40 days of the experiment the bullocks took from 12 to 15 lb. of dried grains per head daily, as against 18 to 19 lb. of hay-chaff. The dried grains, however, were not, after a time, taken so readily by the bullocks, the animals seeming to tire of the food, whereas the hay was eaten steadily: about 7 lb. more water per head daily was taken by the hay-fed bullocks.

The results were :—

	Dried Grains.	Hay.
Gain per head daily, lb.	2·12	2·93
Consumed per head, cwt.	4·6	6·5

Not only were the gains on dried grains less but they were much more irregular than those with the hay-fed beasts, which all increased steadily. The extra cost of the hay was 6s. 6d. only for the whole lot, which was covered ten or twelve times over by the extra gain in weight of the animals.

The conclusion was, therefore, that dried grains could not successfully entirely replace hay.

Hay, 15 lb. daily per head, was then added to the dried grains, and this at once caused the animals to thrive. After 30 days (end of February) the animals consumed less hay and grains, but after 71 days the gains in live-weight had been :—

	Dried Grains and Hay.	Hay only.
Gain per head daily, lb.	2·60	2·20
Average daily consumption, lb. per head	10 of grains 5 of hay	15

The gain in live-weight, 230 lb., resulting from the dried-grains feeding would have more than covered the cost of the grains. Dried grains form therefore a useful addition to hay and can partly replace it.[1]

X. The Use of Condiments for the Feeding of Bullocks.

1900–1.—The addition of spices, condimental foods, or sweetening materials such as locust-bean meal, molasses, etc., has frequently been advocated, but while it is recognised that there may be circumstances under which these can be usefully employed, more especially in the case of hay or other foods in poor condition, no proof is forthcoming of their being really required where foods are well chosen and in good condition, nor that they contribute materially to the gain in weight.

A trial was therefore made of some of these additions to an ordinary good diet of cake, corn, roots, hay, and straw-chaff.

The "ordinary diet" employed was linseed cake 2 lb., decorticated cotton cake 2 lb., maize-meal 2 lb. per head daily, along with hay, oat-straw chaff, and roots all *ad libitum.*

The additions were (*a*) locust-bean meal, (*b*) spices, (*c*) molasses. The locust-meal was used in partial replacement of maize-meal; the other materials tried were given as additions.

The spice was a mixture of liquorice, aniseed, gentian, fenugreek, coriander, carraway, cumin, and ginger; not above 1 oz. per head could be given, and it was found best to let the bullocks have as much of the freshly cut chaff as they would take and then to throw the spice over the remainder. The molasses was mixed with the chaff; $\frac{1}{4}$ lb. per head daily could be taken well, but more than this caused the animals to become "loose."

[1] For details see *J. Roy. Agr. Soc.*, 1898, pp. 768–74.

The results were :—

	Ordinary Feeding.	Locust-bean Meal.	Spice.	Molasses.
Average gain in live-weight per head per day, lb.	1·95	1·67	1·84	1·85

The use of spices, condimental foods, molasses, etc., is therefore not necessary nor advantageous when good and sound ordinary feeding materials are used for fattening bullocks.[1]

SHEEP-FEEDING EXPERIMENTS.

The light sandy soil of Woburn is classed by farmers as "barley and sheep land," and is eminently adapted to having sheep fed on it. The Hampshire and Oxford cross was generally kept at the time of the experiments and was used throughout this work.

I. Comparison of Barley, Malt, and Pea-meal as Additions to Linseed Cake in Sheep-feeding.

1882–3.—The chief object in this experiment was to compare barley with malt as an additional food to linseed cake in the fattening of sheep.

Thirty young sheep of like character were divided up into three pens of 10 each. To each lot linseed cake (¼ lb. daily per head) was given along with swedes, hay-chaff, and straw-chaff, Pen 1 receiving, in addition, ¼ lb. daily per head barley-meal, Pen 2 the malt and malt-dust produced by malting the same weight of barley as used for Pen 1; while to Pen 3 was given, as additional food, ¼ lb. daily of pea-meal: these quantities were gradually increased to 1 lb. daily per head.

The analyses were :—

	Barley-meal. Per cent.	Malt. Per cent.	Pea-meal. Per cent.
Albuminoids	9·56	11·4	22·7
Carbohydrates	63·4	68·3	53·0

[1] For details see *J. Roy. Agr. Soc.*, 1901, p. 299.

The swedes were sliced and fed on the land along with hay and straw-chaff *ad libitum.*[1] After sixteen weeks' feeding the results were :—

112 Days. 10 Sheep per pen.	Pen 1. Linseed Cake and Barley-meal.	Pen 2. Linseed Cake and Malt.	Pen 3. Linseed Cake and Pea-meal.
Gain per head daily, lb. .	0·34	0·38	0·43

It was concluded that malt was somewhat superior to barley as an addition to linseed cake, but that pea-meal was better still.[2]

Another experiment was made in 1891–2 using, however, quantities representing equal money values in barley and malt. An additional pen of sheep received linseed cake without barley or malt. The animals consumed 18 lb. to 19 lb. of roots and nearly ½ lb. of clover-chaff per head daily. The results are given in Table 32.

TABLE 32.—EFFECT OF MALT AND BARLEY IN CONJUNCTION WITH LINSEED CAKE.

93 Days. Sheep per pen.	Linseed Cake (½ lb. rising to 1 lb. daily).	Linseed Cake and Barley (¼ lb. rising to ½ lb. each daily).	Linseed Cake and Malt.
Gain per head daily in live-weight, lb.	0·53	0·45	0·47
Carcass-weight per head, lb. . .	71·4	67·8	68·4

The carcasses were sold at 5s. 4d. per stone of 8 lb. No benefit accrued from using either barley or malt in replacement of linseed cake, and malt did not prove to be better than barley.[3]

II. Home-grown *v.* Purchased Food.

This experiment was made with the same general purpose as that for the bullocks (p. 86).

[1] 15·6 lb. daily of swedes were actually consumed per head during the first eight weeks.

[2] For details see *J. Roy. Agr. Soc.*, 1883, pp. 422–32.

[3] *Ibid.*, 1892, pp. 716–23.

1885–6.—Five pens of 8 sheep (Hampshire and Oxford Down cross), about 10 months old, were selected and given in addition to roots and hay-chaff :—

Pen 1, linseed cake.
Pen 2, linseed cake and undecorticated cotton cake.
Pen 3, wheat-meal.
Pen 4, oats (crushed) and barley-meal.
Pen 5, oats (crushed) and split beans.

Half a pound per head daily of the cake and of the corn was given, and 11 to 12 lb. of swedes per head daily were taken by the sheep at first, this being gradually increased to 20 lb.

At first the sheep did not take very well to the wheat-meal but they took readily to whole wheat. The experiment began on December 3, 1885. About the middle of January and early in February very severe weather set in, and, during this period, the advantage of feeding with cake was very clearly marked. The experiment closed on March 19, 1886, after 106 days' feeding. After taking into account the relative cost of each feeding, the results given in Table 33 were obtained.

TABLE 33.—COMPARISON OF HOME-GROWN AND PURCHASED FOODS.

106 Days. 8 Sheep per pen.	Pen 1. Linseed Cake.	Pen 2. Linseed Cake and Undecorticated Cotton Cake.	Pen 3. Wheat.	Pen 4. Oats and Barley.	Pen 5. Oats and Beans.
Gain in live-weight per head daily, lb. .	0·47	0·39	0·49	0·38	0·38
Cost of food per lb. of live-weight increase .	1·39d.	1·38d.	1·00d.	1·39d.	1·66d.

There was no advantage in substituting linseed cake by cotton cake, and the best gain at lowest cost was given by

[1] For details see *J. Roy. Agr. Soc.*, 1886, pp. 514–24.

wheat. The albuminoid ratios were: linseed cake, 1 : 5·55; wheat, 1 : 6·68.

1886–7.—The experiment, with certain modifications, was repeated in the winter season 1886–7. The quantities of cake and corn were as before, but the season was drier and the sheep rather stronger; after a time they took 27 to 30 lb. of swedes per head daily.

The experiment began on December 23, 1886, and continued for 95 days, until March, 28, 1887; the results were:—

95 Days. 8 Sheep per pen.	Pen 1. Linseed Cake.	Pen 2. Wheat.	Pen 3. Decorticated Cotton Cake.	Pen 4. Linseed Cake and Barley.	Pen 5. Decorticated Cotton Cake and Barley.
Gain in live-weight per head daily, lb.	0·35	0·32	0·40	0·27	0·20
Cost of food per lb. of live-weight increase	1·84d.	1·50d.	1·33d.	1·96d.	2·34d.

These results show that the highest gain was got from decorticated cotton cake at the lowest cost, and wheat came next, being as before superior to linseed cake and to the cake and corn mixtures. As between wheat and linseed cake the results are much in accordance with the conclusion of the 1885–6 experiment, and confirmed that wheat can safely be used as a food for sheep.

The value of decorticated cotton cake was also brought out, and this would be further enhanced if manurial value were taken into account, the diet when decorticated cotton cake was used being the most nitrogenous of all.

The albuminoid ratios of the three best lots were: decorticated cotton cake, 1 : 5; linseed cake, 1 : 7; wheat, 1 : 9.

The sheep fed on linseed cake, however, looked throughout the brightest and healthiest of the lot, and their wool was the most compact and best in quality.[1]

[1] For details see *J. Roy. Agr. Soc.*, 1887, pp. 417–25.

A further comparison of wheat and other cereals was made in the winter 1887–8. The ration of grain began at ¼ lb. per head daily and rose to ¾ lb.; the roots consumed ranged from 17 to 20 lb. daily per head, and the hay-chaff was ¼ lb. The experiment lasted from December 19, 1887, to April 9, 1888 (112 days), and the results were :—

112 Days. 8 Sheep per pen.	Pen 1. Oats.	Pen 2. Barley.	Pen 3. Oats and Barley.	Pen 4. Wheat.	Pen 5 Oats and Wheat.
Gain in live-weight per head, lb.	0·42	0·40	0·42	0·43	0·37
Cost of additional food per lb. of live-weight increase	1·45d.	1·30d.	1·34d.	1·22d.	1·51d.

The differences between the several lots were not great, but the general result was again in favour of wheat.[1]

III. Partial Replacement of Linseed Cake by Wheat or Barley.

1894–5.—This trial was for the purpose of seeing the effect of replacing half of the ration of linseed cake by wheat or by barley. The total cake or cake and corn was at the rate of ½ lb. rising to 1 lb. per head daily. In addition 18 to 20 lb. of roots were consumed daily per head (swedes at first, then

TABLE 34.—PARTIAL REPLACEMENT OF LINSEED CAKE BY WHEAT OR BARLEY AS SHEEP FEED.

82 Days. 20 Sheep per pen.	Linseed Cake.	Linseed Cake and Wheat.	Linseed Cake and Barley.
Gain per head daily in live-weight increase, lb.	·41	·40	·435
Cost of food[2] (including roots and hay-chaff) consumed per head during the entire period	8s. 7d.	7s. 8½d.	7s. 10½d.
Price realised per head	£2 16s.	£2 14s. 8d.	£2 10s. 7d.

[1] For details see *J. Roy. Agr. Soc.*, 1888, pp. 476–80.

[2] Wheat and barley, £1 per qr.; linseed cake, £7 10s. per ton; initial cost of sheep, £2 2s. per head.

mangolds) and about ½ lb. hay-chaff. The results after 82 days are given in Table 34.

Here the barley has done better than the wheat, and as its price stood at 20s. per quarter it profitably replaced part of the linseed cake.[1]

IV. (*a*) Heavy- and Light-feeding with Cake and Corn. (*b*) Is the Inclusion of Hay desirable when Feeding Roots off by Sheep ?

1893–4.—The winter season 1893–4 was altogether exceptional, a prolonged drought in summer resulting in very small crops of hay and a very limited supply of roots.

It was, accordingly, thought well to test comparatively large amounts of cake and corn against a smaller quantity, the more usual ration ; also to see the effect of omitting hay. In these ways, if successful, a shortage of hay and of roots might, it was thought, be met.

The results were :—

Sheep per pen, 20. Food Consumed, average lb. per Head per day.				No. of Days.	Cost of Food per Head.	Gain per Head in Whole Period.	Gain per Head Daily.	Average Carcass-weight.	Average Price Realised, per Head.
Cake.	Corn.	Roots.	Hay.		s. d.	lb.	lb.	lb.	s. d.
0·49	0·49	21	—	80	8 11	32·8	·41	72·1	48 0
0·30	0·30	23	—	101	9 7	35·45	·35	75·6	50 4
0·30	0·30	23	0·29	101	10 11	42·15	·42	78·7	52 6

The slower-growing sheep were the more profitable, and the addition of hay to the ration effected a considerable improvement.[2]

These experiments came in for a considerable amount of criticism. The matter was referred to Lawes and Gilbert, who suggested certain alterations in regard to the methods of

[1] For details see *J. Roy. Agr. Soc.*, 1896, pp. 47–53.

[2] *Ibid.*, 1895, pp. 155–61.

feeding, avoidance of unequal periods over which an experiment was spread, and changes in the methods of taking and recording live- and dead-weights.[1]

A further experiment was therefore made incorporating these recommendations of Lawes and Gilbert ; the purpose was to compare hay with other fibrous foods.

During the first experiment (1895–6), the weather was exceedingly inclement, and several of the sheep died and had to be substituted from the reserves, always an unsatisfactory process. No great importance therefore attaches to the results. The figures suggested as before that the slower growth was the more profitable, and that dried grains formed a better coarse food than hay or oat straw.[2]

In the next experiment (1897–8) a comparison was made between dried grains, oat straw, meadow hay, and oat straw and hay mixed ; ½ lb. rising to 1 lb. linseed cake was fed daily, with about 25 lb. roots per head. The individual sheep were withdrawn and slaughtered as and when a practical member of the Committee thought them fit.

The results are given in Table 35.

TABLE 35.—COMPARISON OF OAT-STRAW, HAY, AND DRIED GRAINS.

98–142 Days. 15 Sheep per pen.	Oat-Straw.	Meadow-Hay.	Oat-Straw and Hay.	Dried Grains.
(*a*) Average daily gain per head in live-weight, lb.	0·40	0·42	0·43	0·41
(*b*) Price realised (carcass-weight) per head .	£2 14s. 6d.	£2 15s. 1d.	£2 16s. 0d.	£2 15s. 6d.
(*c*) Cost of food of all kinds per head[3] .	15s. 6d.	15s. 10d.	15s. 9d.	17s. 0d.

All the foods behaved practically alike. The very slight difference, if significant, is in favour of the oat-straw and

[1] For details see *J. Roy. Agr. Soc.*, 1895, p. 715.

[2] *Ibid.*, 1896, p. 310.

[3] Oat-straw chaff, £1 12s. ; Meadow-hay chaff, £3 5s. ; Dried grains, £4 8s. 3d. per ton with carriage. The average amount of fibrous foods taken daily varied from 0·34 to 0·39 lb.

hay, but it could easily turn in favour of grains if they were cheaper.[1]

V. Economy in Root-feeding.

1901–2.—This experiment was done for the same purpose as the corresponding one with bullocks, viz. to see whether the ration of roots could be advantageously reduced in view of the poor crop of 1901. Forty cross-bred (Hampshire and Oxford) lambs were used, and divided into four lots receiving respectively :—

Pen 1—Full supply of roots,[2] with linseed cake and clover-hay.
Pen 2—Limited supply of roots,[2] with linseed cake and clover-hay.
Pen 3—Limited supply of roots,[2] with linseed cake and gorse.
Pen 4—No roots, but with linseed cake, hay, treacle and water.

The experiment was begun on November 14, 1901, and the sheep were slaughtered as ready. The results are given in Table 36.

TABLE 36.—EFFECT OF RESTRICTION OF ROOT SUPPLY ON GROWTH OF SHEEP.

10 Sheep per pen.	Pen 1. Full Supply of Roots.	Pen 2. Limited Roots.	Pen 3. Limited Roots with Gorse.	Pen 4. No Roots.
Food eaten, lb. per day :				
Roots	17	10	10	—
Hay	0·25	0·25	0·25	2·25
Gain per head in whole period, lb. . .	43·2	40·8	37·6	26·5
Date of slaughter .	Feb. 10	Feb. 24	Feb. 17	March 3
Balance after paying cost of food, per head	+ 4s. 3d.	+ 2s. 9½d.	+ 1s. 7d.	− 7s. 4d.

The full supply of roots did much the best and brought the sheep out earlier, while the withholding of roots involved serious loss. The gorse was not helpful.[3]

[1] For details see *J. Roy. Agr. Soc.*, 1898, pp. 774–86.
[2] Swedes, then kohl-rabi, then mangolds. Full supply : 17 lb. ; limited supply, 10 lb. per head daily.
[3] For details see *J. Roy. Agr. Soc.*, 1902, pp. 338–46.

VI. The Possibility of Early Feeding of Mangolds to Sheep.

1898–9.—This was tried with 10 month-old lambs (Hampshire-Oxford cross), one half of them being males, the other half females. They had been feeding until December 20, 1898, on grass and receiving a few swedes; they were then moved to the arable land and given mangolds instead of swedes, also ¼ lb. linseed cake and ½ lb. of undecorticated cotton cake per head daily with hay-chaff. The sheep appeared to go on quite well and their gains were :—

14 Sheep.	1st Period. 36 Days.	2nd Period. 47 Days.	3rd Period. 28 Days.
Live-weight gain per head daily, lb. . . .	0·47	0·44	0·62

The results compare favourably with those of the other experiments. During the third period a ewe died from inflammation of the lungs, and, later (April 6), a male was found when killed to have diseased kidneys. It is frequently stated that the feeding of mangolds freely tends to act upon the kidneys of male sheep.[1]

1900–1.—The experiment was repeated in the following year with four lots of sheep, two of which received mangolds and two had swedes, with additional foods in each case. The experiment began on November 9, 1900, and, at the start, 12 lb. per head daily of mangolds and 15 lb. of swedes per head daily were given. These amounts proved to be too liberal, as the sheep became "loose"; so the quantities given were cut down to 9 lb. of mangolds and 12 lb. of swedes; undecorticated cotton cake now took the place of the linseed cake first used. It was then found possible gradually to increase the root allowance, and finally, by January 9, 1901, the sheep were having up to 16½ lb. mangolds and the same amount of swedes per head daily. The mangolds

[1] For details see *J. Roy. Agr. Soc.*, 1899, p. 566.

proved superior to swedes and no harm had accompanied their use.[1]

CALF-REARING EXPERIMENTS.

I. The Utilisation of Separated Milk.

Experiments were started in April, 1912, on the rearing of calves on whole milk and on separated milk fed with (*a*) cod-liver oil, (*b*) a purchased calf-meal, (*c*) gruel (made of linseed meal and oatmeal), (*d*) crushed oats.

The calves were fed for the first 3 weeks on whole milk only, then weighed, and divided into the several lots and fed on the assigned rations. The results after 9 weeks are given in Table 37.

TABLE 37.—UTILISATION OF SEPARATED MILK IN CALF-FEEDING. 1ST SERIES. 4 CALVES PER SET.

Food.	Cost per Calf[2] per week.	Gain per Calf per week.	Cost per lb. Gain in Live-weight.	Later Life as Bullocks. Dead-weight.	Average Price per Head.	Balance after paying for Food and Pasturage.
	s. d.	lb.	d.	cwt.	£ s.	£ s.
Whole milk	5 9·2	12·83	5·39	5·9	21 13	7 16
Separated milk and Crushed oats	2 9·6	13·30	2·52	6·0	23 0	10 14
Cod-liver oil	2 8·1	9·66	3·33	6·2	20 10	8 12
Calf-meal	2 0	8·66	2·77	6·6	20 15	6 15
Gruel	2 4·8	8·33	3·45	5·9	21 1	7 2

At the close of the experiment (early June) the calves were turned out into the fields and were all fed alike for 16 months, then in the winter of 1913 they were fattened off in the yards and slaughtered when ready.

[1] For details see *J. Roy. Agr. Soc.*, 1901, pp. 308–16.

[2] The prices of the foods were: whole milk, 7d., separated milk, 2d.; cod-liver oil, 5s. 6d. each per gallon; calf-meal, 15s.; oatmeal, 17s.; linseed, meal, £1 4s.; crushed oats, 7s. each per cwt.

The initial gain in the early period from feeding with separated milk and crushed oats was maintained throughout. Moreover, two out of this lot were ready for the butcher before any of the others, and were followed in order by the whole-milk lot. There was thus, possibly, an added advantage accruing to the separated milk-and-oat feeding of calves as conducing to earlier maturity. The butcher's comments on the quality of the meat were equally satisfactory, the beef of this lot being reported on as "firm and of excellent quality, the fat being evenly distributed throughout the lean." [1]

Similar results were obtained in the following year with autumn-born calves. The feeding, however, extended to 12 weeks (Nov. 10, 1913–Feb. 14, 1914): the results [2] are given in Table 38.

TABLE 38.—UTILISATION OF SEPARATED MILK IN CALF-FEEDING. 2ND SERIES.

Food.	Cost per Calf per week.	Gain per Calf per week.	Cost per lb. gain in Live-weight.
	s. d.	lb.	d.
Whole milk . .	5 3·9	8·3	7·7
Separated milk and Crushed oats .	2 0·2	8·3	2·9
Calf-meal B. . .	1 7·4	6·2	3·1
Cod-liver oil . .	2 0·7	6·5	3·8
Calf-meal A. . .	1 6·7	6·6	2·8
Gruel . . .	2 0·9	5·7	4·3

The greatest gains in live-weight were again obtained with separated milk and crushed oats, and with whole milk, but the cost of the whole milk was higher.

II. Calf-rearing Without the Use of Milk, 1915-17.

The purpose was to ascertain how far separated milk could be dispensed with in the rearing of calves, and whether

[1] For particulars see *J. Roy. Agr. Soc.*, 1914, pp. 51–62.
[2] *Ibid.*, 1917, p. 253.

the additional foods could be given with water in place of milk.

Twenty-four calves were fed for the first fortnight on whole milk only, then weighed and divided on November 3, 1915, into six lots of four, each fed as follows :—

Crushed oats and separated milk.
Crushed oats and water.
Calf-meal and water.
Palm-nut meal and water.
Beans and water.
Maize and water.

It was not nearly so easy to give the foods with water as it had been with separated milk, and different ways of preparing and presenting the foods to the calves had to be adopted. To the crushed oats a little sugar had to be added. The maize (kibbled) was taken best when scalded; the beans, also kibbled, were best taken dry. Palm-nut meal presented the greatest difficulty, and was not taken well either as a gruel or scalded, but only with a little hay-chaff. The crushed oats with separated milk were taken readily from the outset, as also was the calf-meal with water.

After 8 weeks of the special feeding, ¼ lb. of linseed cake per head daily was given to each lot. The results after 12 weeks' feeding are set out in Table 39.

TABLE 39.—USE OF MEAL IN CALF-REARING. 1ST SERIES (12 WEEKS).

12 Weeks. Food.	Cost per Calf per week.	Gain per Calf per week.	Cost per lb. increase of Live-weight.
	s. d.	lb.	d.
Crushed oats and separated milk	2 7	6·6	4·7
Crushed oats and water	10·2	3·7	2·7
Calf-meal with water	1 5	2·85	5·9
Palm-nut meal and water	10·25	6·0	1·7
Beans and water	9·75	4·6	2·1
Maize and water	1 1·6	4·5	3·0

Nothing equalled the crushed oats and separated milk mixture, though palm-nut meal, in spite of the difficulties experienced in getting the calves to take it, came next. Crushed oats with water did not do well.

1916–18.—This experiment was on similar lines to the last one, mixed foods, however, being in some cases used. The results after 14 weeks' feeding are given in Table 40.

TABLE 40.—USE OF MEAL IN CALF-REARING. 2ND SERIES (14 WEEKS).

Food.	Cost per Calf per week.	Gain per Calf per week.	Cost per lb. increase of Live-weight.
	s. d.	lb.	d.
Crushed oats and water	1 2	2·7	5·15
Oats and beans with water	1 5	6·1	2·8
Calf-meal and water	2 4	5·3	5·3
Palm-nut cake and oats with water	1 7·25	7·3	2·6
Palm-nut cake with water	10·8	4·7	2·3
Maize and fish meal with water	1 5·75	7·3	2·4

Palm-nut cake still proved difficult to feed, but the mixture of maize and fish-meal was distinctly promising.[2] Again crushed oats and water did not do well.

Subsequent Experience in Calf-rearing at Woburn has shown that linseed cake ground into meal and made up with warm water into a gruel is very satisfactory for calves, and is readily taken from a bucket provided with tubes ending in India-rubber teats.

Experiments on Ensilage.

Although the practice of ensilage—the preservation of green fodder—had long been employed on the Continent and also in America, it received no serious attention in this

[1] For particulars see *J. Roy. Agr. Soc.*, 1917, pp. 255–7.
[2] *Ibid.*, 1917, p. 257.

country until the 1880's, following the disastrously wet year of 1879. As far back, however, as 1843, Prof. J. F. W. Johnston had written [1] an account of ensilage as practised in Germany. Serious experiments began in 1884. Early in that year Lawes and Gilbert visited W. Gibson's farm at Saffron Walden to examine his system of ensilage, and in May they erected at Rothamsted two silos which were filled during the summer. In mid-June silos were constructed, at Dr. A. Voelcker's instigation, at Woburn out of a barn lent by the Duke of Bedford: these were ready to be filled by mid-July. In addition H. M. Jenkins, then Secretary of the Royal Agricultural Society, prepared a full report on the "Practice of Ensilage at Home and Abroad." [2] This was closely followed by a paper from Dr. Augustus Voelcker (one of the last he wrote) on the "Chemistry of Ensilage," [3] giving analyses of samples of silage obtained from various farms where the process was being tried in this country. He stated his intention of dealing with the influence of temperature on the quality of the silage, and of tracing the changes and losses occurring during the process. His death in December, 1884, prevented his pursuing the enquiry, but the work was continued by J. A. Voelcker.

The silos were rectangular compartments capable of holding 20 to 30 tons of green stuff: they were made by putting brick partitions in a barn, the walls being cemented and 16 ft. high: the floors also were cemented, so that no loss by drainage occurred. The fronts were of jointed boards running in grooves.

The material was filled into the silos in July, 1884, and weighted with planks loaded with boxes of stones, the pressure being about 1 cwt. per sq. foot. Several kinds of silage were made: from pasture grass, clover, and from oats cut green. Temperature observations were taken throughout the storage period, and the general nature and palatability

[1] *Highland and Agricultural Society's Transactions*, 1843-45, p. 60.
[2] *J. Roy. Agr. Soc.*, 1884, pp. 126–246. [3] *Ibid.*, pp. 482–504.

of the sample was recorded. In all cases the material was weighed into the silo, and again as it was withdrawn, thus giving a figure for loss of green weight. Analytical samples taken before and after gave information relating to the losses of the various food constituents.

The first silo was opened on January 8th, 1885. The silage was fed to bullocks and tested against roots and hay providing approximately the same amounts of dry matter, fibre, and nitrogen as the silage. Where grass or clover silage was compared with hay, both silage and hay had been derived from the same crop.

The results of the feeding experiments are summarised in Table 41.

TABLE 41.—LIVE-WEIGHT GAINS FROM SILAGE AS COMPARED WITH ROOTS AND HAY.[1]

Material Ensiled.	Bullocks in each Lot.	Days' Feeding.	Live-weight Gain per Head per day, lb.	
			With Silage.	With Roots and Hay.
Poor quality grass	4	60	0·92	2·33
Good quality grass	4	113	2·06[2]	2·31
Good quality grass	2	54	1·44[3]	1·78
Clover	4	60	0·50	2·20
Oats (cut green)	2	82	2·00[6]	1·33[4]
Oats	2	28	2·43[6]	1·43[4]
Oats	4	42	1·20[6]	0·86[5]

In no case was the silage equal to the ration of roots and hay; but oat silage was superior to roots and chaff, and to hay alone.

With further experience the loss in making the silage was reduced: at first it had been 22 per cent.; at the close of the work it was only about 8 per cent.

[1] *Reference.—J. Roy. Agr. Soc.*, 1886, p. 493; 1886, p. 504; 1886, p. 508; 1886, p. 495; 1886, p. 509; 1886, p. 510; 1886, p. 511.

[2] Sour silage.

[3] Sweet silage.

[4] Straw-chaff instead of hay.

[5] No roots.

[6] Silage 18 months old.

One of the most interesting experiments is on the comparison of silage and hay.[1] A meadow of 5½ acres was cut and the fresh grass carted away in alternate loads, one load going to the silo, the next to a neighbouring piece of grass to be laid out and made into hay. All loads were weighed in, and carefully sampled for chemical analysis; the weights of hay and silage were finally ascertained, and samples taken for analysis. As will be seen from the following figures the feeding values of the hay and silage were almost exactly the same, so that the question had become simply one of the relative cost of making grass hay and grass silage.

The results were :—

Material Ensiled.	Bullocks in each Lot.	Days' Feeding.	Live-weight Gain per Head per day, lb.	
			With Silage.	With Roots and Hay.
Grass	6	84	1·982[2]	1·96

TABLE 42.—LOSS IN ENSILING OR HAY-MAKING, EXPRESSED AS PERCENTAGE OF THE ORIGINAL AMOUNT.

	Green Matter.	Dry Matter.	Total N.	Protein N.	Non-Protein N.
Grass silage . .	7·3	13·6	+ 2·6[3]	40	+ 193 (gain)
Meadow-hay from same grass . . .	67·6	10·3	6·3	0·77	30

100 parts of grass produced :—

Good silage	88·15	Good hay	29·77
Inferior and mouldy silage .	4·56	Inferior hay and waste .	2·61
Loss fermentation and evaporation, etc. . . .	7·29	Water and loss in making hay	67·62

[1] *J. Roy. Agr. Soc.*, 1887, p. 408. [2] *Ibid.*

[3] Apparent gain, presumably experimental error.

The losses of the various feeding constituents in the silage and hay-making processes are given in Table 42.

In making silage there is a pronounced gain in non-protein nitrogen at the expense of the protein nitrogen, whereas in hay-making the non-protein nitrogen is reduced.

These losses were less than in the earlier years: no doubt experience had tended to reduce them. The loss of green weight had varied from 5 to 22 per cent, the mean being 14 per cent: this, however, gives no clue to the loss of dry matter which is the really important thing and may well have been heavier.

The following conclusions were drawn:—

(1) The ensiling of green fodder under conditions which militate against the successful making of hay, succeeded in preserving, as useful succulent fodder, what might otherwise have been largely wasted.

(2) With care and attention to details, the loss in carrying out the process did not exceed 7 to 8 per cent of the green material.

(3) The exclusion of air was secured by careful treading down, especially at the corners and sides of the silo, with subsequent weighting up to 112 lb. to the square foot. The more thorough the exclusion of air, the better was the ultimate material.

(4) Inferior green material did not make good silage, but the process rendered it more acceptable to stock, and provided succulent food for winter use in the absence of a sufficiency of roots, etc.

(5) Silage did not have the full feeding value of the same amount of dry matter in the form of roots and hay, but grass made into silage was practically equal in feeding value to the same weight of grass made into hay.

(6) "Sweet" silage showed no advantage in feeding value over sour silage.[1]

[1] For further details see *J. Roy. Agr. Soc.*, 1886, pp. 483–513; 1887, pp. 403–17.

PART II.—STATISTICAL EXAMINATION OF THE RESULTS.

BY W. G. COCHRAN, B.A.

CHAPTER IX.

METEOROLOGICAL DATA.

THE meteorological observations at Woburn Experimental Farm on rainfall, temperature, and duration of sunshine do not cover the whole period from 1877 to the present date. Observations on the total daily rainfall and daily maximum and minimum temperatures started in September, 1898, and have continued since that date. The monthly totals of rainfall from 1882 to 1897 have already been published.[1] Sunshine records did not start until 1918.

The readings from a meteorological station at Aspley Guise were used to fill the gaps in the records. This station is $1\frac{1}{2}$ miles from the farm and stands 400 feet above sea-level, this being about 110 feet higher than the farm itself. The records on which this study is based are as follows :—

Rainfall	Aspley Guise	1877–1900
	Woburn	1901–1933
Temperature	Aspley Guise	1880–1900
	Woburn	1901–1933
Sunshine	Aspley Guise	1881–1916
	Woburn	1918–1933

Temperature and sunshine records previous to 1880 are, unfortunately, not available, and neither station recorded

[1] *J. Roy. Agr. Soc.*, 1898, vol. 9, p. 726.

the hours of sunshine in 1917, which is accordingly not included in the sunshine figures.

The Aspley Guise rainfall and temperature records were used up to 1900, because Miss Webster had used them in studying the effect of meteorological factors on the yields of wheat and barley. Certain Woburn records previous to that date are, however, available.

From the rainfall figures available for both Woburn and Aspley Guise from 1882 to 1900, Miss Webster compared the annual totals at the two stations. The average annual rainfalls at the two stations differ but little over the period, the figures being 22·66 inches for Aspley Guise and 22·50 inches for the experimental farm. It is remarkable, however, that the difference in favour of Woburn in the annual totals increases steadily throughout the period, at the rate of 0·16 inch per annum, the linear regression being significant at the 1 per cent point. This would indicate that the annual rainfall at Woburn in 1887 was less than that at Aspley Guise by about 1·5 inches, but exceeded it in 1900 by about 1·3 inches. No explanation of the steady increase can be offered.

Miss Webster also compared the distribution of rain throughout the year at the two places in eight harvest years selected from the period. No marked difference was observed, though Woburn was slightly wetter in the summer months June to September and slightly drier in the months November to February.

The temperature readings, unfortunately, overlap for only two years, 1899 and 1900, a period too short to allow of confidence in the small differences which emerge. For no period do the sunshine records overlap.

Occasional references to the weather occur in the field note-books. These refer mainly to the conditions prevailing during the important field operations, such as sowing, applications of the top-dressings, and harvesting; and the most frequent type of entry is one recording delay in the

operations owing to gales or heavy rain. Notes at other times of the year were made only when some exceptional circumstance in the weather appeared to be adversely affecting the crop, such as, for example, a hailstorm in July or a severe frost in March.

This account is divided into two parts, the first a description of the seasonal variation at Woburn within the year, based on averages taken over the whole period 1877–1933, and the second a consideration of points of interest in the variations of weather from year to year throughout the period 1877–1933.

The Seasonal Variation of Weather at Woburn.

Woburn lies in a relatively dry part of England and its rainfall is mainly cyclonic and thunderstorm. It is also in the part which shows the greatest extremes of temperature though it is less sunny than the south of England generally. The relation of the climate at Woburn to that in the part of England in which it lies and to the average climate for England and Wales is more fully shown in Table 43, which gives the averages in the period 1881–1915 of the monthly figures for total rainfall, mean daily temperature, and number of hours of sunshine per day for Woburn, the east of England, and England and Wales.

The figures for the east of England and for England and Wales as a whole are derived from the *Book of Normals of Meteorological Elements* issued by the Meteorological Office. In this, England and Wales is divided into six districts, and the district figures are obtained from a number of representative stations in each. The district, England East, in which Woburn lies, consists of the counties of Norfolk, Huntingdon, Suffolk, Cambridge, Bedford, Hertford, Essex, and Middlesex. The stations from which the district means are obtained all lie to the east of Woburn and nearer to the North Sea. Further, except for Rothamsted, they are all

nearer sea-level. The sunshine and temperature figures given below for England and Wales are obtained by taking the means of all six districts. The estimates thus obtained are not very satisfactory, owing to the relatively small number of stations which they cover, but they appear to be the best available without a great deal of unjustifiable labour. The rainfall figures given for England and Wales are more accurate, being based on estimates of the normal rainfall at a number of uniformly distributed points over the country. They are taken from Table 21A in Section V. of the *Book of Normals*.

TABLE 43.—AVERAGE MONTHLY DATA FOR RAINFALL, MEAN TEMPERATURE AND DAILY SUNSHINE, 1881-1915.

	Total Rainfall: ins.			Mean Temperature: °F.			Sunshine: Hours per Day.		
	Wo-burn.	Eng. E.	Eng. and Wales.	Wo-burn.	Eng. E.	Eng. and Wales.	Wo-burn.	Eng. E.	Eng. and Wales.
Jan.	1·64	1·81	2·99	37·2	37·9	39·0	1·68	1·70	1·53
Feb.	1·45	1·54	2·57	38·5	38·8	39·6	2·41	2·66	2·52
Mar.	1·69	1·69	2·67	42·5	41·1	41·5	3·61	3·87	3·78
Apr.	1·43	1·50	2·12	45·7	45·6	45·7	5·03	5·55	5·36
May	1·90	1·81	2·30	51·5	51·3	51·0	5·97	6·65	6·40
June	1·94	2·01	2·44	57·3	57·1	56·6	6·00	6·86	6·63
July	2·18	2·32	2·87	60·8	60·5	59·7	5·87	6·58	6·36
Aug.	2·25	2·20	3·35	60·0	60·1	59·3	5·81	6·05	5·74
Sept.	1·75	1·89	2·54	55·7	56·2	55·8	4·73	5·15	4·85
Oct.	2·64	2·64	3·97	48·5	49·6	49·5	3·10	3·33	3·13
Nov.	2·23	2·32	3·49	42·4	43·5	44·0	1·97	2·12	1·97
Dec.	2·33	2·28	3·92	39·7	39·5	40·5	1·32	1·33	1·26
Total or Annual avr.	23·43	24·01	35·23	48·3	48·4	48·5	3·96	4·32	4·13

The monthly distributions of rainfall and temperature at Woburn are typical of the east of England generally. Except in spring, Woburn is slightly drier than the district as a whole. It is also colder in autumn and winter and slightly warmer in spring and summer, as is to be expected from the fact that it lies farther from the sea than the other stations. Similarly, the east of England is slightly colder in winter and warmer

in summer than England and Wales as a whole. Woburn also receives less bright sunshine than the east of England generally at all periods of the year. The deficiency is negligible in January, but increases steadily to a maximum of 0·86 hour per day in June and thereafter decreases until December, in which it is again negligible. At Rothamsted, which is the station nearest to Woburn of those from which the district values were compiled, the monthly totals lie

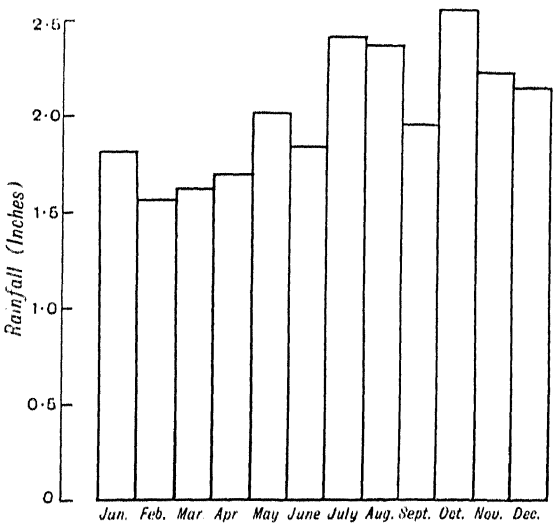


FIG. 1.—Rainfall at Woburn. Average monthly totals in inches (1877-1933).

intermediate between those for Woburn and those for the district, the annual average being 4·22 hours per day.

The averages used above do not cover the whole period from 1877 onwards. The corresponding average monthly figures for total rainfall, maximum and minimum daily temperature, and number of hours of bright sunshine per day for the period 1877–1933 are shown in Figs. 1, 2, and 3. The inclusion of the period from 1916 to 1933 has changed somewhat the monthly distributions, and owing to a series of wet years in the 'twenties the average total rainfall has risen to 24·33 inches. October remains the wettest month

with 2·56 inches; next come July and August with 2·41 and 2·38 inches respectively; then November and December. The driest months are February and March with 1·57 and 1·63 inches respectively.

To turn to the temperature figures, the coldest month is January, with a mean maximum daily temperature of 43·2° F. and a mean minimum night temperature of 32·8° F., just above freezing-point. In February the night minimum

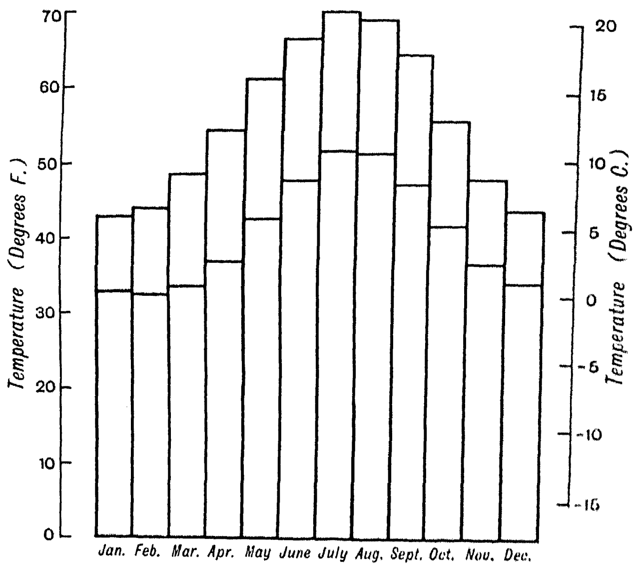


FIG. 2.—Average monthly means of maximum and minimum daily temperatures at Woburn (1880-1933).

remains about the same, but the day maximum has increased by a degree. Both maximum and minimum increase thereafter until July, the hottest month, which has a mean maximum of 70·0° F. and a minimum of 51·4° F. August is about a degree cooler than July both during the day and at night. From September to January the temperature falls steadily, the fall from month to month being more rapid than the corresponding rise in spring and early summer. The average daily range of temperature also behaves similarly,

increasing from 10·4° F. in January to 18·8° F. in August and then falling again.

The sunshine figures follow the same course, except that the least and the greatest sunshine values occur one month

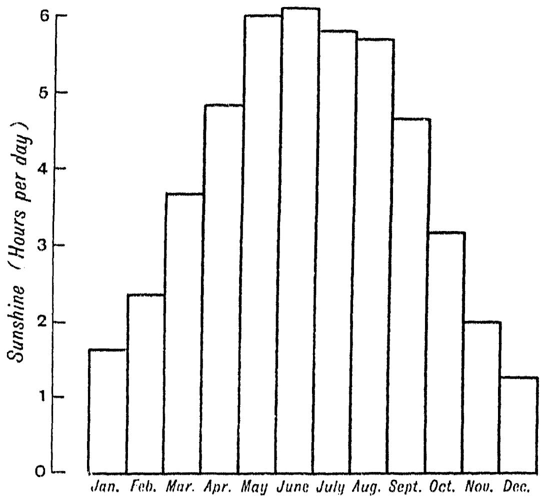


FIG. 3. Average number of hours of bright sunshine per day at Woburn (1877-1933).

earlier, in December, with 1·27 and June with 6·10 hours per day respectively.

Fluctuations in Weather Throughout the Period 1877-1933.

In the preceding section the average variations throughout the year at Woburn in rainfall, sunshine, and temperature were described. Few individual years of the period, however, conform closely to the average; and practically every one has some exceptional feature. A few years have been picked out in the present section as showing outstanding deviations from the normal in one or other of the chief meteorological factors. For comparison with individual years, the average annual figures in 1877–1933 for rainfall, mean temperature, and sunshine are :—

MEAN FOR YEAR.

Rainfall	24·33 inches
Mean temperature . . .	48·2° F.
Sunshine	1441 hours

MEAN FOR MONTHS.

Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total or Mean.
Rainfall : ins.												
1·82	1·57	1·63	1·71	2·03	1·85	2·41	2·38	1·96	2·56	2·24	2·17	24·33
Mean Temperature : ° F.												
37·8	38·5	41·1	45·6	51·9	57·1	60·7	60·1	55·8	48·6	42·2	38·8	48·2
Sunshine : hours.												
50·8	66·6	114·4	144·2	185·6	183·8	180·2	177·6	140·2	98·4	59·9	39·4	1441·1

The variation in total annual rainfall about the average of 24·3 inches is not simply a random one from year to year.

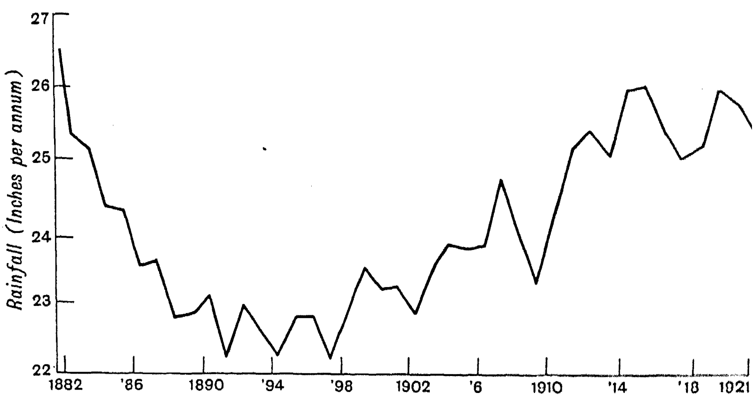


FIG. 4.—Running 10-year means of annual rainfall at Woburn.

The period consists of two wet spells of years, extending roughly from 1877 to 1886 and from 1909 to 1928, separated by a dry one from 1887 to 1908, as shown in the diagram (Fig. 4), which gives the 10-year means of the annual rainfall figures. The series of wet years with which the long-term experiments commenced actually extended back to about 1870. Of the 10 years from 1877 to 1886, only 1878 and 1884

were below normal, and the average annual rainfall in the period was 26·0 inches. The wettest years of the period were 1880, with 28·5 inches, and 1882 with 29·2 inches. The period of dry years from 1887 to 1908 is equally noticeable, the mean annual rainfall being only 22·5 inches. All years of the period had rainfall below the average except 1891, 1894, 1903, and 1906. Of these, 1903, with 34·5 inches, was the wettest year of the whole period 1877–1933. After 1908 began the second sequence of wet years, and 16 of the next 22 years received excess rainfall. Curiously enough, in this wet spell occurred the driest year of the whole period, 1921, with only 14·2 inches. Whether the wet spell is now giving place to another dry one it is too early to say. Of the last 5 years of the period, 1929–33, 1931 was the only one substantially above the average in rainfall, and 1934 has also proved a dry year. These systematic changes in the annual rainfall of the past 60 years are not confined to Woburn. They were shown to exist at Rothamsted by R. A. Fisher [1] in 1924, and appear to have taken place in all parts of the country.

The year 1879 was remarkable for rainfall. The six summer months from April to September were all unusually wet, totalling 19·3 inches, 7 inches more than normal. This resulted in a poor harvest, as seen in the returns for the year from the permanent wheat and barley experiments. The wet summer and autumn were followed by a winter of exceptional dryness, the rainfall totals in the succeeding four months being October 0·69, November 0·67, December 0·56, and January 0·41 inches.

The months in which frosts are most frequent and severe at Woburn are January and February. There was severe frost for 3 weeks in January, 1881, the mean temperature for the month being 29·1° F. The night minimum reached the low figure of 6·9° F. This year also saw some very

[1] R. A. Fisher, *Phil. Trans.*, B, 213, 1924 (p. 117).

warm weather in July, the day temperature reaching 90·7° F. on the 15th.

The years 1891, 1894, and 1898 are interesting, because the yields of wheat on the permanent plots in these years stand out well above the average yields for the period. In all 3 years the normal harvest month, August, was wetter than usual, and in fact in 1891, in which 4·4 inches fell in August, the harvest was delayed till September. The remainder of the harvest year, however, from the preceding September to July, was deficient in rain, the totals of rainfall being 16·0 inches in 1890–1, 19·7 inches in 1893–4 and 17·2 inches in 1897–8, whereas the average for these 11 months is 21·9 inches. None of the harvest years was particularly sunny, 1890–1 and 1897–8 being deficient in sunshine and 1893–4 just over the average; and of the summer months May, June, and July in these 3 years, all were deficient in sunshine except July, 1898.

The years differed somewhat as regards the severity of the winter. In 1890, September and October were mild, and the early part of November was dull and wet. On November 25 frost set in which lasted well into January. The mean daily maximum temperature for the month of December was 31·6° F., just under freezing-point, the mean night minimum being 23·3° F. On the 22nd December the night minimum was 2·3° F., nearly 30° below freezing-point. The remainder of the harvest year continued colder than usual, only February and June having mean temperatures above normal. The winter of 1893–4, on the other hand, was of about average temperature, with short periods of frost in the first 10 days of January and in the middle of February; and the winter of 1897–8 was very mild, with no severe frost, all 5 months October to February being warmer than usual. The weather of the latter season is aptly described in the field note-book of the permanent wheat plots for that year: "The wheat came up well, and favoured by the mild winter got very forward during the early spring.

It received a check later from the abnormal drought during part of March and April. A very wet May, however, more than recompensed for the previous drought and ensured a heavy crop of straw, and thanks to a hot July a good yield of corn as well."

The cold spell in 1891–2 was followed in 1895 by another, the most remarkable cold period in the records. At Woburn this lasted throughout January and February, except for a few days in the middle of January. The mean temperature in January was 31·2° F. and in February 27·3° F.

The year 1903 has already been mentioned as the wettest year of the period. The excess of rainfall, 10·2 inches, occurred in the months May to October, which were unusually wet, and received in all 23·9 inches, 10·7 inches above normal. February, on the other hand, had only 0·67 inch.

The year 1911 is noteworthy on account of its fine warm spring and summer. All six months April to September were warmer and sunnier than usual, July having 297 hours of bright sunshine, an average of 9·6 hours per day. August had a few exceptionally hot days, the temperature on the 9th rising to 94·2° F. in the shade. Except for March, which was just over the average, the first 7 months were all deficient in rain, and the drought, combined with the warm sunny weather, resulted in low yields on all the permanent plots except those receiving farmyard manure.

1921, the driest year in the records, was similar to 1911. Both will be remembered on account of the shortage of water in most parts of the country; and the drought in 1921 has been frequently compared with the more recent one in 1933. At Woburn no month in 1921 had more than 2 inches of rain, and the only one above normal was January, with 1·91 inches. February, June, and July each received less than half an inch of rain. The drought was aggravated by the exceptional warmth, November being the only month not up to the average temperature, while January exceeded the average by 7·0° F., July by 4·3° F., and October by 7·2° F. The

ground became baked, and barley made very poor growth that year. Wheat withstood the effects rather better, and though the yield on most plots was down, the plots receiving complete artificials or farmyard manure gave better yields than usual.

The year 1924, the second wettest on record with 33·3 inches, is on the whole similar in its rainfall distribution to 1879 and 1903, which have already been described. After a wet January, there followed two very dry months, February and March receiving in all only 1·2 inches. Every month thereafter was wet, particularly May with 5·8 inches, easily its highest total in the period.

To give some idea of the range of variation shown in the period, the highest and lowest observations on a few of the weather factors are listed below. Most of them have already been mentioned above :—

Greatest rainfall in a year	34·47 ins. in 1903.
Least ,, ,, ,,	14·22 ,, 1921.
Greatest ,, ,, month	6·29 ,, Oct. 1903.
Least ,, ,, ,,	0·00 ,, Feb. 1891.
Highest shade temperature	94·2° F. on Aug. 9, 1911.
Lowest ,, ,,	2·3° F. on Dec. 22, 1891.
Most sunshine in a year	1766 hours in 1893.
Least ,, ,, ,,	1191 ,, ,, 1888.
Most ,, ,, month	297 ,, ,, July, 1911.
Least ,, ,, ,,	13 ,, ,, Dec., 1890.

Systematic Changes in the Amount and Seasonal Distribution of Rainfall.

One of the most interesting features of the weather variation in the past 60 years at Woburn, is the way in which the period divides itself into two series of wet years separated by a series of dry ones. From the calculations necessary in investigating the influence of rainfall on the yield of wheat and barley on the permanent plots, it is possible to test the significance, in the statistical sense, of these systematic changes. A similar test was made at Rothamsted over the period 1854–1918 by Fisher,[1] to which reference should be

[1] *Phil. Trans.*, B, 213, 1924.

made for the details of the method. A brief account of the results for Rothamsted and Woburn will be given here.

The method depends essentially on describing the rainfall distribution in any year by means of a fifth-degree polynomial fitted to the totals of the rainfall in each 6-day period. This enables the distribution each year to be determined by means of six constants, a′, b′, c′, d′, e′, f′, of which a′ is proportional to the total amount of rain in the year, and b′, . . . f′ specify the distribution. Systematic changes in the total annual rainfall throughout the period were studied by fitting fifth-degree polynomials to the values of a′ from 1854–1918. The method also enables changes in the distribution of rain throughout the year to be studied by fitting similar polynomials to b′, c′, . . . f′. Fisher found that the slow changes in a′ and d′ both approached the 5 per cent level of significance. The slow change in a′, i.e. in the total annual rainfall, was similar to that found for Woburn. Only 6·7 per cent of the total variation in annual rainfall at Rothamsted throughout the period, however, was ascribable to the systematic change; and, as at Woburn, the wettest year of the period, 1903, occurred in the dry spell and the driest year, 1921, is one of the wet spells. The slow change in d′ consisted of an approximately uniform increase throughout the period of 0·61 per annum. This is more difficult to interpret. From examination of the monthly totals, Fisher was of the opinion that the change in distribution consisted mainly of an increase in December rainfall with perhaps some relative reduction in spring and autumn.

A further investigation into the nature of this change was made by Wishart,[1] who also extended the period of study to 1929. The distribution of rainfall throughout the year at Rothamsted is roughly similar to that at Woburn, with a maximum in October and a minimum in March. Wishart showed that the change in the distribution could be described as a change in the time at which the maximum

[1] J. Wishart, *Memoirs Roy. Met. Soc.*, 3, 1930 (No. 27).

rainfall occurred, and calculated that it had advanced by about 12 weeks during the period 1854–1929. From such records as exist previous to 1850, he concluded that the advance was not a permanent feature of the climate in this country, and pointed out that in the last few years of the period 1854–1929 there were indications that the curve was beginning to recede again.

The detailed examination of Wishart was not extended to the Woburn rainfall data, but the changes in the six coefficients a′, . . . f′ in the period 1877–1926 were examined. The variation in a′ is best fitted by a cubic curve, which is significant at the 5 per cent level and accounts for 13·3 per cent of the total variation in the period. The 10-year means of the total annual rainfall, which is proportional to a′, are shown in Fig. 4, and may be compared with the corresponding diagram given by R. A. Fisher.[1] The slow change in d′ at Woburn is similar in direction to that at Rothamsted, but the rate of increase is only 0·31 per annum, and is not nearly significant. There are also signs of the fall in d′ towards the end of the period to which Wishart drew attention at Rothamsted. It seems likely that there is a slow change in the distribution of the same character as at Rothamsted, though probably not so marked. The agreement, however, is to be expected, since the two stations lie within 30 miles of each other.

[1] *Phil. Trans.*, B, 213, p. 117.

CHAPTER X.

EXAMINATION OF THE RESULTS OF THE CONTINUOUS WHEAT AND BARLEY EXPERIMENTS.

Slow Changes in Yield.

THE data which were statistically examined were the annual yields of grain and straw per acre on all plots on Stackyard Field from 1877 to 1926. The examination itself was almost entirely the work of Miss A. M. Webster; and the present chapter is a report on the conclusions reached. On the permanent wheat and barley series, the investigation falls mainly into two parts: (1) the effects of the manures on yields in the period 1877–1926; (2) the effects of the rainfall on yields. The latter will be considered in the following chapter. The rotation experiments, which were also in Stackyard, will be considered in Chapter XIII. The manures applied on the permanent wheat and barley plots are shown in Table 109.

The Annual Yields.

The annual yields of the plots fluctuate considerably from year to year (cf. Tables 110–13). Examination of any plot in the tables shows that in addition to random fluctuations there are definite slow changes. On most of the barley plots, for instance, the yields show an upward trend in the first 6 or 7 years, after which they fall with varying rapidity until 1926. The same two types of change occur in the principal factors influencing yield. Since the manuring remained constant from year to year on most of the plots, the condition of the soil, considered as a source of plant nutrients,

changed—in most cases deteriorated—slowly and continuously throughout the experiments. Meteorological conditions, on the other hand, may be expected to show random year to year fluctuations only, though in Chapter IX certain slow changes in the amount and distribution of the rainfall have been noted.

Smooth curves fitted to the yields of Barley grain.

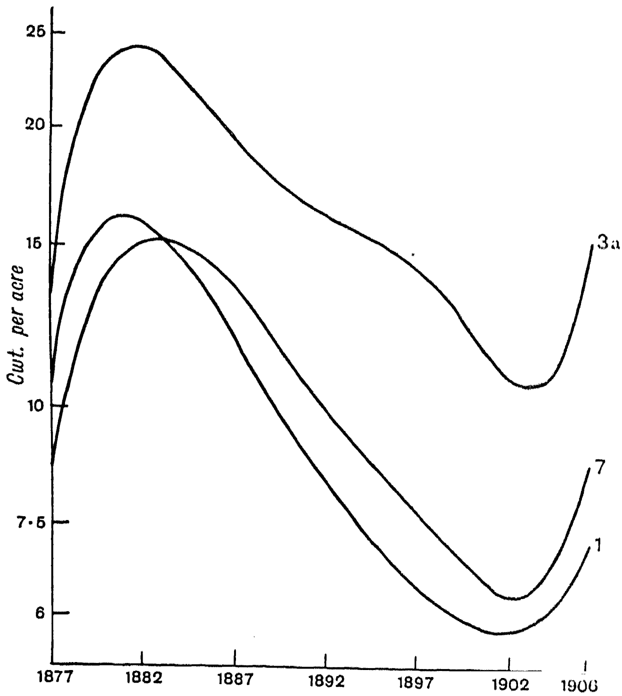


FIG. 5.—Barley grain.
Plots 1, 7: no manure.
3: nitrate of soda only

In this investigation we are concerned mainly with the effects of the manuring and of the rainfall on yields. Slow changes in yield are naturally ascribed to factors which themselves change slowly and continuously, and of these the most important is soil deterioration. To separate the slow changes from the random fluctuations, a smooth curve

is fitted to the annual yields of grain, as has been done for the yields on Broadbalk, Hoos, and Barnfields at Rothamsted. Fifth-degree polynomials were fitted to the yields of

Smooth curves fitted to the yields of wheat grain.

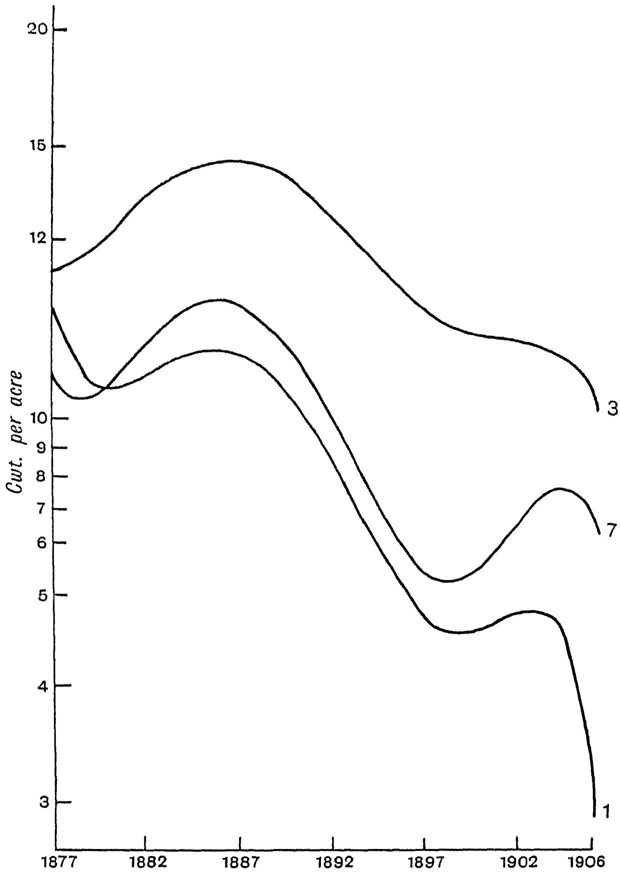


FIG. 6.—Wheat grain.
Plots 1, 7: no manure.
3: nitrate of soda only.

Plots 1, 2a, 3, 4, 5a, 6, 7, 8 (both halves), 9 (both halves) and 11b, and these curves represent the slow changes which have taken place. The values given by the curves are also the

most suitable figures to use in comparing the yields of two plots; the curve, in fact, is an average in which that part of yield representing variation due to weather conditions

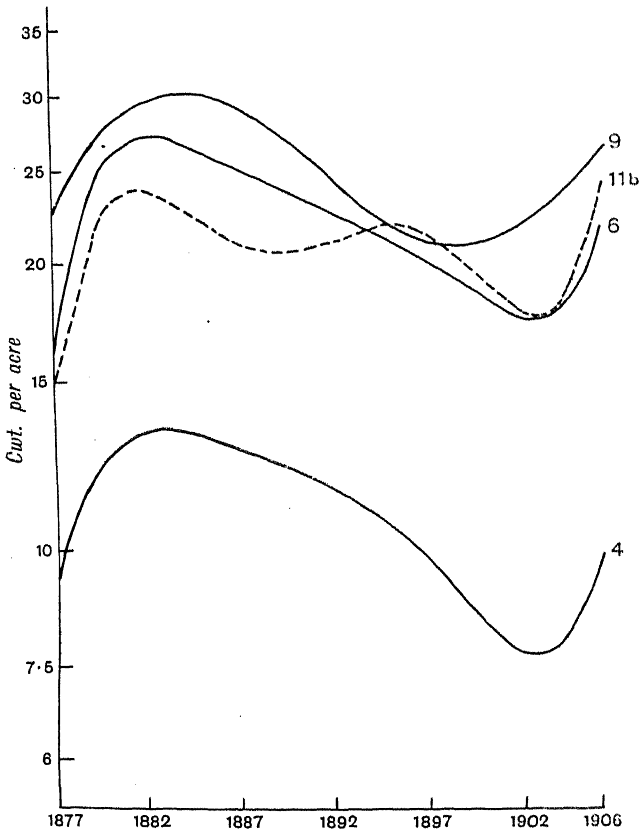


FIG. 7.—Barley grain.

Plots 4: minerals only, no nitrogen.
6: minerals plus nitrate of soda (41 lb. nitrogen per acre).
9: minerals plus nitrate of soda (82 lb. nitrogen per acre).
11b: farmyard manure (105 lb. nitrogen per acre).

and experimental error has been smoothed out. The deviations of the annual yields from the curves afford material for examining the effects of weather, and in particular of rainfall, on yields.

The sudden changes in manuring in 1907 led to variation of another type, and their effect was that the values about which the annual yields were fluctuating dropped abruptly in 1907. Thus if we were to fit a smooth curve to the

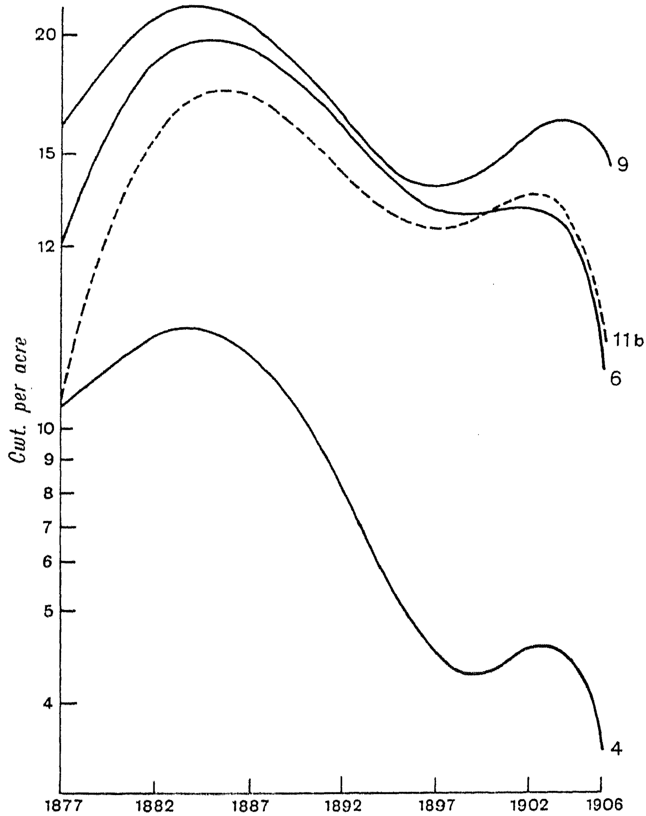


FIG. 8.—Wheat grain.

Plots 4: minerals only, no nitrogen.
6: minerals plus nitrate of soda (41 lb. nitrogen per acre).
minerals plus nitrate of soda (82 lb. nitrogen per acre).
11b: farmyard manure (105 lb. nitrogen per acre).

50 years' data (1877–1926), it would lie too low in the years immediately preceding 1907 and too high in those following it, and we should not obtain a true separation into slow changes and annual variation. For this reason the curves

have been fitted only to the 30 years, 1877–1906, during

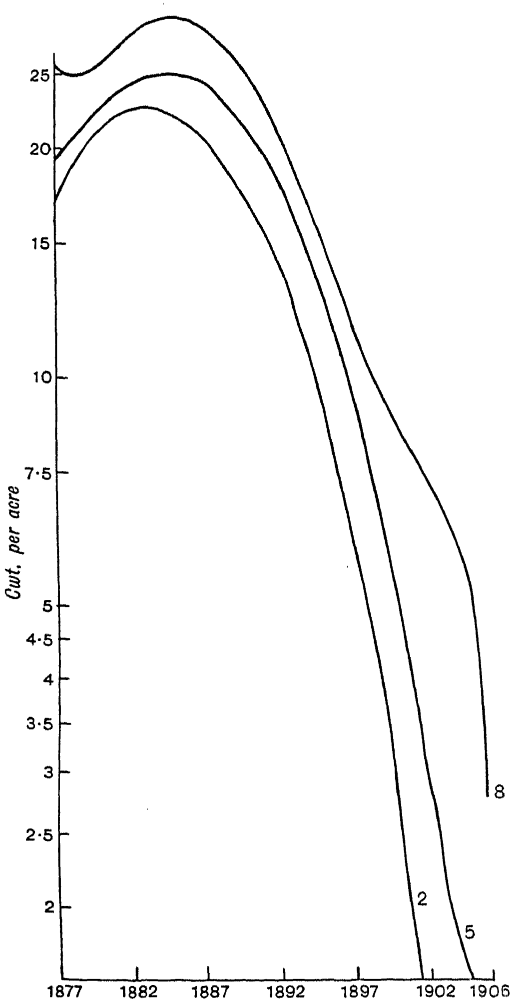


FIG. 9.—Barley grain.

Plots 2: ammonium salts only (41 lb. nitrogen per acre).
5: minerals plus ammonium salts (41 lb nitrogen per acre).
8: minerals plus ammonium salts (82 lb. nitrogen per acre).

which the manuring was constant (except for the changes on 8, 9 in 1882). The curves are shown in Figs. 5–10, which are plotted on a logarithmic scale, so that equal slopes on two curves represent equal percentage changes.

Changes in variety at long intervals would introduce similar disturbing effects on a much smaller scale. On both fields, however, the varieties were changed fairly frequently, and their effects, if any, would show mainly in the deviations from the curves. It is, of course, difficult to disentangle these

effects from those of other annual factors, and examination of the deviations in years when the variety changed on one field but not on the other failed to detect any clear effect of variety on yields.

The slow changes are generally separated into that part which can be represented by a straight line and the remainder. The linear part, which represents a steady drop in yield from year to year, is generally attributed to soil deterioration. The effect of soil deterioration is, of course, not strictly linear; over a long period we would expect yields to fall less sharply in the later part than in the earlier and finally to approach a fixed level, if the only long-term influence at work were soil

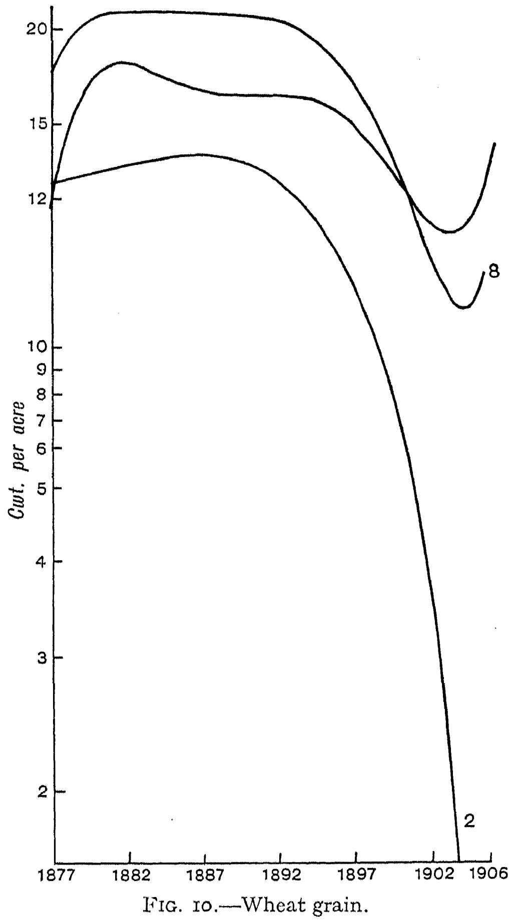


FIG. 10.—Wheat grain.

Plots 2: ammonium salts only (41 lb. nitrogen per acre).
5: minerals plus ammonium salts (41 lb. nitrogen per acre).
8: minerals plus ammonium salts (82 lb. nitrogen per acre).

deterioration. The assumption that the effect is mainly linear over the 30 years considered is reasonable, however, and enables us to look for other factors influencing the slow changes. The significance of this steady deterioration and of the other slow changes can be tested statistically. The deteriorations were significant on all the plots, except 4, 11b (barley), and 3, 5, 11b (wheat). The other slow changes were negligible except on the barley plots 2, 5, and 8. On these plots the changes are explained by the increasingly rapid fall in yields when the plots became acid. Apparently the only factor which the curves show to be definitely influencing slow changes in yields is the deterioration of the soil. From what has been said above about the effect of soil deterioration, we should expect the quadratic terms in the polynomials to have positive coefficients. The coefficients are, in fact, all negative; but this is clearly due to the rise in yields which took place at the beginning of the experiment.

The curves representing the slow changes in yield are calculated from the yields of grain in bushels per acre. In the discussion of the effects of manurial treatments, the yields are generally expressed as cwt. or lb. of grain and straw per acre. The variations throughout the experiment in the weight in lb. of a bushel of grain and in the ratio of grain to total produce may thus conveniently be discussed here.

Bushel Weight.

Tables 44, 44A shows the 5-year averages of bushel weight on the principal plots. The average bushel weight in 1877–1926 was 51·8 lb. for barley and 58·7 lb. for wheat, both of which are below the weights generally obtained on British farms. The weights do not change much with time. The wheat figures rise gradually until 1906–12, after which there is a slight falling-off. The barley weights rise similarly, but the fall-off occurs sooner and is a little more sharp. The

TABLE 44.—FIVE-YEAR AVERAGES OF BUSHEL WEIGHT. WOBURN BARLEY.

Plot.	Manuring.	1877–1881.	1882–1886.	1887–1891.	1892–1896.	1897–1901.	1902–1906.	1907–1911.	1912–1916.	1917–1921.	1922–1926.	Mean.
1 and 7	Unmanured	51·3	51·6	51·4	51·0	52·6	52·1	50·8	49·7	49·4	51·1	51·1
2a	Sulphate of ammonia only	51·8	52·2	52·8	50·8	53·6	52·0 (3)	—	52·5 (4)	49·7 (3)	54·0 (2)	52·1 (37)
3a	Nitrate of soda only	50·8	52·6	51·2	51·1	51·6	52·0	50·8	49·9	48·4	52·2	51·1
4a	Minerals only	51·5	51·9	52·0	51·3	53·3	53·0	50·5	50·3	50·2	50·7	51·5
5a	Sulphate of ammonia and mineral manures	52·0	54·5	53·5	52·6	53·8	52·4	51·3 (3)	53·4 (3)	50·1 (4)	52·6 (3)	52·7 (43)
6	Nitrate of soda and mineral manures	52·0	54·0	52·5	52·5	54·0	53·0	51·2	49·9	49·6	50·1	51·9
8a and b	Sulphate of ammonia applied	52·4	53·5	51·9	52·2	54·0	53·8	51·6 (3)	53·0 (2)	51·3	47·0 (2)	52·4 (42)
	Sulphate of ammonia omitted	—	53·8	53·0	52·5	55·0	52·9	52·0 (2)	55·0 (2)	51·0 (3)	51·0 (2)	53·1 (34)
9a and b	Nitrate of soda applied	51·7	52·9	50·3	52·2	53·7	52·9	51·7	49·6	50·3	50·5	51·6
	Nitrate of soda omitted	—	53·8	53·2	53·0	54·5	53·0	51·4	50·2	50·4	51·3	52·3 (45)
10a	Unmanured to 1906. Then nitrate of soda and superphosphate	—	52·1 (7)	51·8 (2)	51·7	53·2	53·1	51·7	49·5	50·2	50·5	51·6 (44)
10b	Farmyard manure to 1887. Then rape cake	50·9	52·9 (6)	52·1 (2)	52·2	53·4	52·7	52·3	50·1	51·9	51·7	51·9 (48)
11a	Unmanured to 1906. Then sulphate of potash and nitrate of soda	—	53·2	52·7	52·1	53·2	53·3	51·4	49·2	50·4	51·1	51·8 (45)
11b	Farmyard manure	52·8	53·5	53·1	53·0	53·6	54·1	51·9	51·2	51·1	51·6	52·6

The figures in brackets denote the number of years over which the bushel weight has been averaged, when a change in manuring, or lack of crops, prevent a "5-year" period being taken.

TABLE 44A.—FIVE-YEAR AVERAGES OF BUSHEL WEIGHT. WOBURN WHEAT.

Plot.	Manuring.	1877–1881.	1882–1886.	1887–1891.	1892–1896.	1897–1901.	1902–1906.	1907–1911.	1912–1916.	1917–1921.	1922–1926.	Mean.
1 and 7	Unmanured	55·6	57·1	56·7	59·9	61·4	60·0	61·2	58·8	58·9	58·3	58·8
2a	Sulphate of ammonia only	55·9	57·0	57·4	58·9	61·6	56·7 (3)	60·0 (2)	57·0 (1)	58·0 (2)	60·0 (1)	58·2 (34)
3a	Nitrate of soda only	54·1	55·3	54·1	57·4	57·2	57·1	57·2	57·0	57·0	57·6	56·4
4a	Minerals only	55·7	57·8	57·9	59·9	61·5	59·7	61·3	58·8	58·1	58·1	58·9
5a	Sulphate of ammonia and mineral manures	56·6	59·0	58·3	61·1	62·9	60·8	61·7	58·0	58·6	58·4 (4)	59·6 (49)
6	Nitrate of soda and mineral manures	57·0	58·9	56·8	59·0	60·1	59·2	59·5	57·8	58·3	57·7	58·4
8a and b	Sulphate of ammonia applied	57·2	59·2	56·9	61·7	62·3	61·0	59·4	60·0 (3)	60·0	60·3 (3)	59·8 (46)
	Sulphate of ammonia omitted	—	58·6	57·9	60·7	62·7	58·5 (4)	61·2	57·0 (2)	59·2	61·0 (2)	59·8 (38)
9a and b	Nitrate of soda applied	57·4	58·2	54·5	57·9	60·1	59·5	59·9	57·7	58·7	59·3	58·3
	Nitrate of soda omitted	—	58·2	57·1	60·5	61·8	60·0	61·2	58·7	58·6	58·9	59·4 (45)
10a	Unmanured to 1906. Then nitrate of soda and superphosphate	—	57·7 (7)	57·0 (2)	59·8	62·1	60·0	59·7	58·2	58·2	58·2	59·0 (45)
10b	Farmyard manure to 1887. Then rape cake	57·9	58·6 (6)	58·1 (2)	60·3	61·3	60·6	61·6	60·0	59·0	59·5	59·7
11a	Unmanured to 1906. Then sulphate of potash and nitrate of soda	—	58·1	57·3	59·9	61·7	60·6	60·0	58·2	59·2	57·9	59·2 (45)
11b	Farmyard manure	57·9	58·8	57·9	60·2	60·7	60·7	60·6	58·8	59·0	58·3	59·3

The figures in brackets denote the number of years over which the bushel weight has been averaged, when a change in manuring, or lack of crop, prevent a "5-year" period being taken.

weights are highest on Plots 5, 8 (complete minerals and sulphate of ammonia), and 11b (farmyard manure). In the case of wheat the plots receiving nitrate of soda have lower weights than the corresponding plots without, but for barley this is true only of Plots 9a and 9b. Sulphate of ammonia gives higher weights than nitrate of soda for both wheat and barley.

The slow changes in bushel weight appear to have no relation to those in yield. No relation was found between bushel weight and the proportion of corn returned as tail corn.

The variation in bushel weight from plot to plot is so small that it is immaterial whether comparisons are made in bushels or in lbs. All figures in this and the following chapter are given in cwt. or lb., except possibly when comparison with Rothamsted is being made.

Ratio of Grain to Total Produce.

The ratios of the 5-year averages of the yields of grain to those of total produce are given as percentages in Table 126, p. 363. Like the bushel weight figures, the ratios do not change much ; the average ratios in the first 30 years were 35 per cent for wheat and 44 per cent for barley. For both wheat and barley the ratios rose at first. The barley figures averaged 42 per cent in the first 5 years ; thereafter they rose to 45 per cent and remained at that level until 1907. After the change in manuring the ratios dropped to about 40 per cent and fluctuated about that level with a further fall in the years 1922–6. The wheat ratios also rose after the first 5 years from 31 per cent to about 36 per cent ; but unlike barley they showed no tendency to fall until the last 5 years of the experiment, in which the average dropped to about 29 per cent.

Manuring has not had much effect on the ratios, except that they are generally lower on the nitrate of soda plots than

on the corresponding no-nitrogen plots. Sulphate of ammonia gave high ratios, and these remained high in the early years of acidity and did not fall until the yields had become very low. The fall in the ratios may be partly explained, but to an unknown extent, by the increase in weeds when the yields fell. The same remark applies to the general fall in the ratios on both series towards the end of the 50 years, and it is not possible to say definitely whether this fall indicates a change in the plant under starvation conditions.

The slow changes in the ratios resemble those in bushel weight much more closely than they do those in yield; in fact, apart from the fall in the ratios towards the end, there appears to be no connection between slow changes in the ratios and slow changes in yield. It is interesting to examine whether a season which favoured high yields also gave high ratios, that is, whether a positive correlation exists between deviations of the ratios from the long-term values and similar deviations in yields of total produce. It was not possible to use deviations from the long-term polynomials for the yields, because similar polynomials were not fitted to the ratios, and a rather less accurate method was taken. The 30 years 1877–1906 were divided into five equal periods, and the regressions of the ratios on the yields in cwt. per acre were worked out for the deviations of the annual figures from the corresponding 6-year means. Plots 2, 5, and 8 were omitted, since, owing to the rapidity of the long-term changes on these, the deviations taken would not represent the effects of the season on yield.

The regression coefficients were positive and significant on Plots 1, 4, and 7 (barley) and 4 (wheat), while that for Plot 7 (wheat) was near the ·05 level of significance. The regression coefficients for Plots 1, 4, and 7 are given in Table 45.

Thus an increase of 1 cwt. per acre in total produce raises the percentage of grain by about 0·5 for barley and 0·4 for

TABLE 45.—REGRESSION OF RATIO OF GRAIN TO TOTAL PRODUCE ON YIELD OF GRAIN. YIELDS IN CWT. PER ACRE.

	Barley.	Wheat.
Plot 1	+ ·571 (1 per cent significance)	+ ·263
Plot 7	+ ·357 (5 per cent significance)	+ ·350.
Plot 4	+ ·552 (1 per cent significance)	+ ·443 (5 per cent significance).

wheat on the plots receiving no nitrogenous manure. On Plot 3 the regression coefficients were both positive, but did not approach significance. On Plots 6, 9, and 11b, however, the regression coefficients were all negative, though the only significant coefficient was that for 11b (barley). This indicates that on the plots receiving complete manures the straw increases more than proportionately in a good year, so that the percentage of grain tends to fall, whereas on the plots receiving minerals only or no manure the percentage rises in a good year.

The Validity of the Comparisons Between the Different Plots.

It is well known that the fertility of different plots in the same field may vary widely. Before ascribing a difference in the mean yields of two plots to differences in manuring, an estimate is required of the differences in yield on plots receiving the same manures. This is the principle underlying the replication of treatments in modern field experiments.

On the wheat and barley series, the only two plots similarly treated on the same field are 1 and 7, which had no manure. No exact test of the statistical significance of any difference in yields is therefore possible. Plots 1 and 7 are at opposite ends of the field and are separated by 4. 1 is at the same end as 2 and 3, 7 as 8 and 9. The differences in yield between Plots 1 and 7 give some indication of the fertility differences at the two ends of the field. These are best studied from the long-term polynomials (Figs. 8, 9). The curves shown there refer only to the first 30 years, but

as the manuring remained unchanged on 1 and 7 throughout the experiment, 50-year curves were also fitted for these plots. They give substantially the same results as the 30-year curves in 1877–1906. Of the wheat plots, 7 was better throughout than 1, except in the first year or two; of the barley plots, 1 gave higher yields for the first 5 years, but afterwards showed heavier deterioration, so that 7 was better until about 1907. Thereafter, until 1926, 1 was the better plot. The relative fertility of the two barley plots thus appears to have been changing throughout the 50 years.

The principal manurial comparisons below are generally made on the mean yields in cwt. per acre in the first 30 years or in the last 20. For 1 and 7 these are given in Table 46.

TABLE 46.—COMPARISON OF THE TWO UNMANURED PLOTS, WHEAT AND BARLEY.

	Grain.			
	Barley.		Wheat.	
	1	7	1	7
Mean Yield:				
1877–1906 .	8·6	8·4 cwt. per acre	6·7	7·5 cwt. per acre
1907–1926 .	4·3	3·7 ,, ,, ,,	4·5	4·9 ,, ,, ,,
	Straw.			
Mean Yield:				
1877–1906 .	10·9	10·1 cwt. per acre	13·0	13·6 cwt. per acre
1907–1926 .	7·4	6·1 ,, ,, ,,	7·7	7·9 ,, ,, ,,
	Total Produce.			
Mean Yield:				
1877–1906 .	19·5	18·5 cwt. per acre	19·7	21·1 cwt. per acre
1907–1926 .	11·7	9·8 ,, ,, ,,	12·2	12·8 ,, ,, ,,

It is clear that differences in mean yield of the order of 1 cwt. of grain or 2 cwt. of total produce per acre are not significant. Fortunately, there are few doubtful cases; the differences in total produce of the mean yields of plots whose comparisons are of interest are generally either at least 8 cwt. per acre or under 2 cwt. per acre.

In some cases, however, we are comparing mean yields over shorter periods, say 5 or 10 years. These comparisons have generally been made in lb. per acre, and 5-year means of the differences in yield of grain and straw of 1 and 7 are shown in Table 47.

TABLE 47.—DIFFERENCES IN YIELD OF PLOTS 1 AND 7 (5-YEAR MEANS).

Grain.	1 and 7.		lb. per Acre.		
	1877–81	1882–86	1887–91	1892–96	1897–1901
Barley . .	273	144	62	−161	−166
Wheat . .	47	−108	−14	−160	−6
	1902–06	1907–11	1912–16	1917–21	1922–26
Barley . .	− 30	75	90	56	64
Wheat . .	−290	−62	−55	−96	3
Straw.					
	1877–81	1882–86	1887–91	1892–96	1897–1901
Barley . .	329	145	150	−79	−70
Wheat . .	− 23	38	− 56	−144	+38
	1902–06	1907–11	1912–16	1917–21	1922–26
Barley . .	12	131	170	198	60
Wheat . .	−245	− 60	5	− 18	7

The greatest differences in the grain figures above are 45 per cent of the mean yield for wheat and 22 per cent for barley. The usual differences, however, were much less.

Another point which lessens the accuracy of the comparisons is the subdivision of some of the plots in 1882, and later when lime was added. When this has been done, the yield of a half or even quarter plot has to be taken as representative of the whole, though different parts of a plot may differ considerably in fertility. It is, however, impossible to say to what extent this has affected the conclusions.

The circumstance that fertility differences have not been eliminated from the comparisons forces us to view with some suspicion any results emerging from the data which are in conflict with those deduced from other experiments on the same question.

Mean Yields in Relation to Manurial Treatment.

Owing to the change referred to in 1907, the periods 1877–1906, 1907–26 are generally considered separately. In the first period, comparisons are best made by referring to the graphs of the polynomials (Figs. 5-10). The most important manurial effects are as follows.

Nitrogen in the Form of Nitrate of Soda.

The mean yields of grain, straw, and total produce in cwt. per acre for the first 30 years are given in Table 48.

TABLE 48.—MEAN YIELDS OF GRAIN, STRAW, AND TOTAL PRODUCE FIRST 30 YEARS, 1877–1906.

Plot.	Nitrogen Applied, lb. per Acre.	Mean Yield Barley.			Mean Yield Wheat.		
		Grain.	Straw.	Total Produce.	Grain.	Straw.	Total Produce.
				With Minerals.			
4	0	9·6	10·9	20·5	6·8	13·3	20·1
6	41	19·3	24·7	44·0	15·2	28·3	43·5
9	82	22·2	31·8	54·0	17·0	35·3	52·3
				Without Minerals.			
1 and 7	0	8·4	10·5	19·0	7·1	13·1	20·2
3	41	14·7	19·0	33·7	11·0	21·9	32·9

In every case the addition of nitrate of soda has raised the yields. Further, for both wheat and barley the increments (both actual and percentage) of Plot 6 over Plot 4 are greater than those of Plot 3 over the mean of 1 and 7, so that nitrate of soda is more effective in the presence of minerals. The additional increments given by the double dose are much smaller than the first increments, but after 1882 the comparison is unfair, since the half of Plot 9 from which the yield was estimated had received no nitrogen in the previous year. In the first 5 years the mean annual

increments of grain and straw (in cwt. per acre) are given in Table 49.

TABLE 49.—MEAN ANNUAL INCREMENTS OF GRAIN AND STRAW, CWT. PER ACRE, FIRST 5 YEARS, 1877–81.

	Plot.	Barley, cwt. per Acre.		Wheat, cwt. per Acre.	
		Mean Yields.	Increase.	Mean Yields.	Increase.
Grain	4	10·0	—	8·6	—
	6	19·0	9·0	14·4	5·8
	9	21·5	11·5	17·3	8·7
Straw	4	13·0	—	19·3	—
	6	26·6	13·6	31·7	12·4
	9	33·2	20·2	41·8	22·5

It will be noticed that the average increments of 6 over 4 are about four times the greatest average differences between 1 and 7 tabulated above (p. 141), so that there is no question that this is a real effect. As far as can be judged from the first 5 years, the double dose of nitrate of soda has not given double the increment of the single dose.

The slow changes in the nitrate of soda plots can be compared with those on the corresponding no-nitrogen plots by means of the curves (Figs. 5-8). For barley the curves show a rise in yields until about 1882; the curve for Plot 4 falls rather less steeply than the curve for Plot 6 until about 1892, after which it drops more steeply, while 1 and 7 are falling more steeply than 3 from 1884 onwards. The slopes of the curves represent percentage, and not actual, deteriorations, and on this criterion the addition of nitrate of soda has slightly lessened the deterioration on the barley plots. In the corresponding wheat plots the difference due to the presence of nitrate of soda is much more marked both with and without minerals. For both wheat and barley, 9 deteriorated less than 6. It cannot be concluded from this, however, that a true double dose would have shown less deterioration than the single dose, since the total crop removed from Plot 9

over a period of years was less than that removed from Plot 6.

The nitrate of soda and no-nitrogen plots may be compared in terms of four distinct types of increment, which must be clearly distinguished. These are (1) the actual increment of yield (in cwt. per acre); (2) the increment per lb. of nitrogen supplied; (3) the increment expressed as percentage of the yield of the no-nitrogen plot over which the increment was measured, and (4) the percentage increment per lb. of nitrogen supplied. The first three are shown for grain in Table 49A. In the first 30 years the actual

TABLE 49A.—INCREMENTS GIVEN BY NITRATE OF SODA ON YIELD OF GRAIN. GRAIN LB. PER ACRE.

Nitrogen in Manure, lb. per Acre.		Barley. Increment. Actual.	Barley. Increment. per lb. N.	Barley. Per Cent. Increase.	Wheat. Increment. Actual.	Wheat. Increment. per lb. N.	Wheat. Per Cent. Increase.
		Plot 3.	*No Minerals.*				
41	1877–91	765	19	64	420	10	45
41	1892–1906	623	15	87	445	11	70
41·0	1907–26	263	6	58	480	12	93
20·5	1907–26	148	7	33	348	17	66
		Plot 6.	*Minerals.*				
41	1877–91	1198	29	100	976	24	102
41	1892–1906	995	24	106	914	22	104
20·5	1907–26	363	18	60	500	25	108
		Plot 9.	*Minerals.*				
82	1877–91	1492	—	124	1151	—	120
82	1892–1906	1334	—	142	1148	—	205
41·0	1907–26	596	—	99	511	—	98

increments (1) fell for both wheat and barley, while the percentage increments (3) remained about the same for barley and increased for wheat in that period. Owing to the changes in the amount of nitrate of soda supplied, comparison of the

first 30 and the last 20 years is best made by means of the increments (2) and (4) per lb. of nitrogen supplied. The barley increments (2) of grain per lb. of nitrogen fell from 15 lb. previous to 1906 to 7 lb. in the last 20 years on Plot 3, and from 24 lb. to 18 lb. on Plot 6; the wheat increments, on the other hand, rose slightly from 11 to 15 lb. on 3 and from 22 to 27 on 6. The percentage increments (4) per lb. of nitrogen showed no fall for barley in the 50 years and a rise for wheat (Table 49A).

The comparisons per lb. of nitrogen supplied between the first 30 and the last 20 years are not, however, very satisfactory, because we do not expect the effect of nitrate of soda on increment to be linear, and Plot 3a alone retained the same amount of nitrate of soda per acre.

Effect of Minerals.

In the absence of nitrogen, the minerals appear to have had little beneficial effect on wheat. The mean yield of Plot 4 in the first 30 years is as low as that on the unmanured Plots 1 and 7, and in its variation in yield throughout the period, as seen from the curves, it is quite indistinguishable from them. For barley the minerals curve lies below the mean of 1 and 7 in the first 10 years; but the effect of minerals in retarding the general fall in yields can be seen on the curves by 1883 and the average deterioration is much less, the mean yield being 9·6 cwt. of grain per acre against 8·5 for the mean of 1 and 7. The beneficial effect on barley continued in the last 20 years, in which the dressing of minerals was reduced to 3 cwt. of superphosphate and 2½ cwt. of sulphate of potash per acre. The mean yields were 5·4 cwt. per acre on 4 and 4·0 on 1 and 7. There is perhaps also some sign of an effect on wheat in the last 10 years, in which 4 gave consistently better yields than 1 and 7, though the differences were small.

In the presence of nitrogen, minerals are much more

effective in increasing yields. The mean yields of grain of Plots 6 and 3 during 1887–1906 are :—

Plot.	Barley.	Wheat.
6	19·3 cwt. per acre.	15·2 cwt. per acre
3	14·7 „ „ „	11·0 „ „ „

Owing to acidity, the sulphate of ammonia Plots 2 and 5 are comparable only in the first 15 years, during which the mean yields of grain were :—

Plot.	Barley.	Wheat.
5	20·1 cwt. per acre.	16·2 cwt. per acre.
2	17·6 „ „ „	12·9 „ „ „

Further, for barley the curve for Plot 6 is much less steep than that for Plot 3, which shows that the minerals added to 6 have counteracted the rather heavy deterioration produced when nitrate of soda alone is applied. For wheat there is little to choose between the slopes of 3 and 6, though deterioration is not very marked on either. The results indicate, however, that neither in presence nor in absence of nitrogen has the absence of minerals accelerated the fall in yields for wheat as it did for barley.

Comparison of Potash and Superphosphate.

Previous to 1906, the minerals supplied were 3½ cwt. superphosphate, 200 lb. sulphate of potash, 100 lb. sulphate of soda, and 100 lb. sulphate of magnesia, these being the same amounts as used on the Hoos barley field at Rothamsted. On Hoos the experiments were laid out so as to compare the relative effectiveness of the constituents of the minerals applied in three ways : (1) alone, (2) with nitrate of soda, (3) with rape cake ; on this rather heavy soil superphosphate markedly increased yields of barley, but sulphate of potash slightly decreased them. In 1907 an attempt was made to see which of sulphate of potash and superphosphate was effective on the light sandy soil of Woburn, in presence of nitrate of soda. Plots 10a and 11a had been without manure

since 1882, except for rape cake on 10a in 1889 and farmyard manure on 11a barley in 1888 by a mistake. From 1907 until 1926 they each received the same dressing of nitrate of soda as Plots 3b and 6 ; 3b had no other manure, 10a had 3 cwt. superphosphate, 11a had 1 cwt. sulphate of potash, and 6 had 3 cwt. superphosphate and ½ cwt. sulphate of potash.

Little can be learned from the data, except perhaps that this type of experiment is unsuitable for testing the point at issue. For during 1877–82, 11a had received double the dressing of farmyard manure given to 10a, and owing either to the residual effect of this or to the fact that 11 was an exceptionally good plot, of which there are indications, 11a gave consistently higher yields than 10a for both wheat and barley in the years 1882–1906. The average annual difference between the yields of the two plots in the 5 years preceding the experiment was 612 lb. total produce per acre for barley and 425 lb. per acre for wheat. Further, 6 and 3b are equally unsuitable for comparison ; 3b had received nitrate of soda annually for 30 years but no minerals, and it may be expected that by 1907 the soil would be in a state of mineral exhaustion. Plot 6, on the other hand, received only half the dressing of potash given to 10a in 1907–26.

In the circumstances probably the best thing to do is to ignore Plots 6 and 3b and regard the years 1902–6 as giving a uniformity trial on Plots 10a and 11a. The mean yields of total produce in the two periods were :—

	Barley.		Wheat.	
	1902-6.	1907-26.	1902-6.	1907-26.
11a Potash	2675	2726 lb. per acre.	2431	2526 lb. per acre.
10a Phosphate	2063	2212 ,, ,, ,,	2006	2639 ,, ,, ,,
Diff.	612	514 ,, ,, ,,	425	−113 ,, ,, ,,

Thus 10a gained 98 lb. per acre on 11a as a result of the two treatments on barley, and 538 lb. per acre for wheat. This indicates that there is nothing to choose between potash and superphosphate for barley, but for wheat superphosphate

is the more beneficial. The average annual decrements in the 20 years concerned (1907–26) were :—

	Barley.	Wheat.
11a Potash	102·9 lb. per acre.	53·4 lb. per acre.
10a Phosphate	65·9 " " "	72·1 " " "

which indicates that for barley deterioration was less on the plot receiving superphosphate, while for wheat deterioration was less on the plot receiving potash. The figures are not very reliable, however, owing to the shortness of the period. It is difficult to draw any definite conclusion from the results as a whole.

Effect of Farmyard Manure.

In the first 10 years, two plots, 10b and 11b, received farmyard manure containing approximately 53 and 105 lb. of nitrogen per acre respectively. After 1886 the single dressing was discontinued. The mean yields in the first 10 years are shown in Table 50 (Plot 4 minerals only) being included for comparison.

TABLE 50.—EFFECT OF FARMYARD MANURE. MEAN YIELDS, 1877–86 : CWT. PER ACRE.

	Barley.			Wheat.		
	Plot 4.	Plot 10b.	Plot 11b.	Plot 4.	Plot 10b.	Plot 11b.
Grain	10·7	14·4	19·0	9·0	10·9	14·0
Increase	—	3·7	8·3	—	1·9	5·0
Straw	13·5	17·8	23·0	18·3	21·8	27·5
Increase	—	4·3	9·5	—	3·5	9·2

The double dressings gave rather more than twice the increments of the single dressings over the yield of Plot 4. It is not suggested, however, that the deviations from proportionality, which are quite small, represent a real effect.

The long-term polynomials show that the farmyard manure plots maintained their yields better than any other

plots; in fact, there was practically no deterioration in either wheat or barley yields in the first 30 years. The yields continued high in the last 20 years, during which the dressing was reduced to 82 lb. nitrogen per acre. The mean yields of grain in the two periods 1877–1906, 1907–26 were 18·5 and 13·6 cwt. per acre for barley, and 14·0 and 10·3 cwt. per acre for wheat, the figures for 1907–26 being in both cases the highest for all plots on their respective fields. The corresponding grain figures for Plot 6 (nitrate of soda and minerals) were: barley, 19·3 and 8·6 cwt. per acre; wheat, 15·2 and 9·2 cwt. per acre.

The increments per lb. of nitrogen supplied were much smaller for farmyard manure than for complete artificials, but the effectiveness of farmyard manure on barley relative to nitrate of soda increased throughout the period owing to the smaller deterioration of the former. Table 51 shows the

TABLE 51.—INCREMENTS PER LB. OF NITROGEN SUPPLIED IN FARMYARD MANURE AND IN NITRATE OF SODA.

	Increments per lb. of Nitrogen Supplied per Annum.			
	Barley: lb. per Acre.		Wheat: lb. per Acre.	
	Farmyard Manure.	Nitrate of Soda + Minerals.	Farmyard Manure.	Nitrate of Soda + Minerals.
Grain 1877–1891 .	8	29	6	24
1892–1906 .	10	24	8	22
1907–1926 .	11	18	8	25
Straw 1877–1891 .	9	44	11	46
1892–1906 .	15	35	16	36
1907–1926 .	16	24	17	41

increments (over Plot 4) per lb. of nitrogen supplied in the manure given by farmyard manure and nitrate of soda. The quantities of nitrogen per acre in the two manures were: farmyard manure, 105 lb. (1877–1906), 82 lb. (1907–26); nitrate of soda, 41 lb. (1877–1906), 20 lb. (1907–26).

To judge by the increments of grain, the effectiveness of farmyard manure on barley was only about 25 per cent of that of the single dressing of nitrate of soda in presence of minerals in the early years of the experiment, but rose to 60 per cent. in the last 20 years. For wheat, on the other hand, there was little change in the relative effectiveness.

Effect of Sulphate of Ammonia.

In the first 15 years, the yields on the sulphate of ammonia plots were similar to those on the corresponding nitrate of soda plots. As with nitrate of soda, the comparison of the single (41 cwt. nitrogen per acre) and the double dressings is confined to the first 5 years, in which the mean yields were as shown in Table 52, the nitrate of soda plots being included for comparison.

TABLE 52.—EFFECT OF SULPHATE OF AMMONIA AND OF NITRATE OF SODA I SINGLE AND DOUBLE DRESSINGS. FIRST 5 YEARS MEAN YIELDS (1877–81).

	Barley: cwt. per Acre.				Wheat: cwt. per Acre.			
	Grain.		Straw.		Grain.		Straw.	
	Mean.	Increase.	Mean.	Increas	Mean.	Increase.	Mean.	Increase.
Plot 4 (mins.) . .	10·0	—	13·0	—	8·6	—	19·3	—
Plot 5 (mins. + 1 sulphate of ammonia)	18·6	8·6	25·2	12·2	14·2	5·6	31·0	11·7
Plot 8 (mins. + 2 sulphate of ammonia)	22·2	3·4	31·0	5·8	17·9	3·7	41·1	10·1
Plot 6 (mins. + 1 nitrate of soda)	19·0	9·0	26·6	13·6	14·4	5·8	31·7	12·4
Plot 9 (mins. + 2 nitrate of soda)	21·5	2·5	33·2	6·6	17·3	2·9	41·8	10·1

The yields on the sulphate of ammonia and nitrate of soda plots were remarkably close. For straw nitrate of soda gave slightly higher yields, the ratio of the increments due to the single and double dressings being about the same.

The additional increases of grain to the second dressing were, however, less for nitrate of soda than for sulphate of ammonia.

The mean yields in the first 15 years (1877–91) on the sulphate of ammonia and nitrate of soda plots and the corresponding plots without nitrogen are shown in Table 53.

TABLE 53.—EFFECT OF SULPHATE OF AMMONIA AND NITROGEN OF SODA, SINGLE AND DOUBLE DRESSINGS. FIRST 15 YEARS. MEAN YIELDS (1877–91.)

	Barley: cwt. per Acre.				Wheat: cwt. per Acre.			
	Grain.		Straw.		Grain.		Straw.	
	Mean.	Increase.	Mean.	Increase.	Mean.	Increase.	Mean.	Increase.
Plot 4 (mins.) . .	10·7	—	12·7	—	8·5	—	17·5	—
Plot 5 (mins. + 1 sulphate of ammonia)	20·1	9·4	24·5	11·8	16·2	7·7	31·3	13·8
Plot 8 (mins. + 2 sulphate of ammonia)	23·6	3·5	32·1	7·6	20·2	4·0	41·0	9·7
Plot 6 (mins. + 1 nitrate of soda) . .	21·4	10·7	28·7	16·0	17·3	8·8	34·4	16·9
Plot 9 (mins. + 2 nitrate of soda) . .	24·0	2·6	36·7	8·0	18·8	1·5	43·4	9·0
Plots 1 and 7 (no manure) . .	10·7	—	13·2	—	8·5	—	16·9	—
Plot 2 (1 sulphate of ammonia) . .	17·6	6·9	21·4	8·2	12·9	4·4	24·0	7·1
Plot 3 (1 nitrate of soda)	17·5	6·8	23·2	10·0	12·3	3·8	25·1	8·2

This brings out the same features as does Table 52, namely, higher yields of straw, and a slightly smaller increase of grain to the double dressing with nitrate of soda.

After 1891 the yields on the sulphate of ammonia plots fell with increasing rapidity, owing to the marked acidity which set in on these plots. On all plots except 5 (wheat), the yields fell ultimately to under 4 cwt. of grain per acre, and frequently there was no measurable crop. For barley the percentage rates of deterioration after 1890 were practically the same for Plots 2, 5, and 8, as the long-term polynomials show (cf. Fig. 9). Of the wheat plots receiving

minerals, 5 showed a much less severe fall in yields than 2 and returned an average yield of 7·0 cwt. of grain per acre in the last 20 years. The yields on Plot 8, however, while better maintained than on any other sulphate of ammonia plot, fell ultimately just as steeply as on Plot 2. The 5-year means of the yields of grain on the unlimed portions of the plots in question from 1882 to 1926 are shown in Table 54.

TABLE 54.—MEAN YIELDS OF GRAIN: CWT. PER ACRE ON PLOTS RECEIVING SULPHATE OF AMMONIA WITHOUT LIME.

Plot.	1882–86.	1887–91.	1892–96.	1897–1901.	1902–06.	1907–11.	1912–16.	1917–21.	1922–26.
Barley:									
2	19·7	16·2	9·5	3·5	0·3	0·0	1·0	0·6	0·9
5	22·4	19·2	14·2	5·0	2·1	1·4	1·6	2·2	2·6
8	26·5	22·2	14·7	9·6	5·0	2·7	0·8	1·2	0·5
Wheat:									
2	14·8	12·6	12·4	8·3	1·7	0·6	0·2	0·5	0·1
5	18·4	16·0	14·9	15·1	12·6	10·0	7·7	0·8	3·3
8	22·6	20·2	17·3	16·5	10·1	3·7	1·9	3·2	1·0

The fall in yields occurred later for wheat than for barley, but, except on Plot 5, was just as severe.

Effect of Lime.

From 1897 onwards, certain sulphate of ammonia plots were subdivided; and lime was applied to certain parts in various amounts and at various times. None of the dressings was heavy, 4 tons per acre in 1897–1926 being the greatest. Since comparisons are in most cases based on the yields of quarter plots, it is not worth while discussing each application separately. The actual amounts of lime given and the times of application are shown in the table of manures, p. 350. Except on Plots 2aa, the lime was applied either in one or two doses.

Plots 2b, 2bb, 5b, 5aa (barley), 8aa, and 8bb show the effect of total dressings of 4, 2, or 1 tons per acre applied in

one or two doses, in presence and absence of minerals and on the residual sulphate of ammonia plots. The general effect of the dressings appears to have been the same in all cases. The first dressing raised the yields at once well above those of the corresponding unlimed plots, the increase being greatest where the initial yields were smallest. A downward trend, fairly rapid, set in at once. Where a second dressing was given, the yields were again raised at once, though the increase in yield was smaller than with the first dressing. The downward trend set in again at the higher level. The only exception was Plot 2 (wheat); one half, 2b, was divided into 2b and 2bb in January, 1905, the latter quarter receiving 2 tons lime per acre. The yields of 2b and 2bb, however, remained similar from 1905 to 1926. It is not certain here that the lime was ineffective, as the quarter which received the extra dressing may have been in a worse state than the other. Both quarters had previously received 2 tons lime per acre in 1897.

It is reasonable to expect that if sufficient lime were given the sulphate of ammonia plots would rise to about the level of the corresponding nitrate of soda plots. The sulphate of ammonia yields tended to fall away from the nitrate of soda yields about 8 years after the application of the dressing, and comparison of the limed sulphate of ammonia and the corresponding nitrate of soda plots is best made by the mean yields during the first 5 years after each application of lime. Table 55 shows these means, and also the amounts and years of application of the lime.

With barley the first dressing of lime raised the sulphate of ammonia yields to the level of the nitrate of soda yields in all cases shown above except on Plot 2, the plot on which yields were lowest previous to the application of lime. The second dressing raised the yields on the sulphate of ammonia plots above those on the nitrate of soda plots in all four cases. With wheat the sulphate of ammonia yields were above the nitrate of soda yields in two cases out of four after the first

TABLE 55.—MEAN YIELDS OF GRAIN DURING THE FIRST 5 YEARS AFTER LIMING.

Plot.	Barley: cwt. per Acre. First Dressing.	Yield.	Barley: Second Dressing.	Yield.	Wheat: cwt. per Acre. First Dressing.	Yield.	Wheat: Second Dressing.	Yield.
2bb (sulphate of ammonia) .	2 tons 1897	11·9	2 tons 1905	13·6	2 tons 1897	10·6	2 tons 1905	9·1
3b (nitrate of soda)		13·4		11·5		11·3		9·9
5b (sulphate of ammonia) .	2 tons 1897	18·5	2 tons 1912	11·8	1 ton 1905	14·4	...	...
6 (nitrate of soda)		18·5		9·7		12·1		...
8aa (sulphate of ammonia) . .	2 tons 1897	21·0	2 tons 1912	12·6	½ ton 1905	14·0	½ ton 1918	7·8
9a (nitrate of soda)		21·6		10·9		15·1		9·6
8bb (sulphate of ammonia) . .	2 tons 1897	16·6	2 tons 1912	9·1	½ ton 1905	11·0	½ ton 1918	7·2
9b (nitrate of soda)		13·5		8·1		6·7		5·6

dressing. The two plots—2bb and 8aa—which were below the corresponding nitrate of soda plots after the first dressing remained slightly below them after the second dressing.

Plots 2aa, wheat and barley, received respectively 1 and 1½ tons per acre in small doses, mainly of 5 cwt. per acre each. These were quite effective considering their size; the mean yields of grain were 5·0 cwt. (wheat) and 9·7 cwt. (barley) per acre, as against 0·4 and 0·6 cwt. per acre on 2a (no lime).

A dressing of 1 ton per acre was given to one half, 4b, of the barley Plot 4 (minerals only) in 1915. In 10 of the remaining 12 years the yield of this half was above that of the other, but the differences were small, the mean yields of grain being 5·9 and 5·1 cwt. per acre.

The nitrate of soda plots 3a and 3b were subdivided for liming in January, 1921, 2 tons per acre being given to 3aa and 3bb. The limed parts both gave better yields in 1922, but otherwise there was no apparent effect.

Effect of Rape Cake.

In 1889 rape cake was applied to the whole of Plot 10, the amount given supplying 50 lb. of ammonia, or 42 lb. nitrogen per acre. From 1890 until 1906 double this amount was given, but to one half, 10b only, the other half remaining without manure. After 1906 the amount given was quartered. The rape cake applications followed 10 years of farmyard manure (containing 53 lb. nitrogen per acre), and as farmyard manure appeared to have a residual effect on these fields, part of the yield from 1890 onwards may be due to this, though it is not possible to say how much.

Until 1906 the rape cake proved very successful in maintaining yields for both crops, there being no sign of deterioration in either case (Table 56).

TABLE 56.—RAPE CAKE AND FARMYARD MANURE. MEAN YIELDS (1890–1906): CWT. PER ACRE.

Plot.	Barley.		Wheat.	
	Grain.	Straw.	Grain.	Straw.
10b (rape cake = 83 lb. N. per acre) .	17·7	20·6	14·6	25·1
11b (F.Y.M. = 105 lb. N. per acre) .	19·0	22·8	13·7	24·6

Per lb. of nitrogen supplied rape cake was considerably more effective than farmyard manure for wheat, but about equally effective for barley.

The yields fell for both crops as soon as the dressing was reduced in 1907, and continued to fall until the end. The percentage fall was, however, steeper for barley than for wheat, the average decrease each year in the yield of grain in the last 20 years being 50 lb. or 7·1 per cent of the mean yield for barley, and 49 lb. or 5·0 per cent. for wheat. The mean yields in the period were: barley, grain 6·3 cwt. per acre; straw, 9·6 cwt. per acre; wheat, grain 8·7 cwt. per acre; straw, 14·1 cwt. per acre. By 1916 the barley plot

had reached about the same level of yield as the plot receiving minerals only; the wheat plot, however, remained well above Plot 4, and continued to compare very favourably per lb. of nitrogen supplied with the farmyard manure plot, whose mean yields in the last 20 years were: grain, 10·3 cwt. per acre, straw, 20·2 cwt. per acre.

On the whole, rape cake was much more effective for wheat than for barley. Two factors may have contributed to this difference in effect. The rape cake plots became more acid as time went on, which probably accounts for part of the rapid decline in barley yields after 1906. There was also a small difference in the time of application of the rape cake for the two crops, the wheat dressing given generally from 15 to 40 days before the barley. The times of application varied widely, however, throughout the period.

Residual Effect of Nitrogenous Manures.

Two of the Broadbalk plots at Rothamsted, 17 and 18, receive mineral manures every year, but their ammonium salts in alternate years only. The comparison of the yields of each plot in the years without nitrogenous dressing with the yields of the plot never receiving nitrogen but only minerals (Plot 5) gives a measure of the residual effect. The mean yields and the rates of deterioration of yield are the same for these plots, so that at first sight there appeared to be no residual effect. The plot testing residual effects, however, showed considerably greater variability in yield from year to year than Plot 5, and in its reaction to rainfall showed more resemblance to the plots receiving ammonium salts every year than to the plot receiving mineral manures only. This suggested that some residue of nitrogenous material was left in the soil by the previous year's dressing. If this were so the apparent lack of response might be due to soil heterogeneity.

In 1882 Plots 8 and 9 at Woburn were halved to permit of a similar comparison, both halves thereafter till 1926

receiving mineral manures every year but nitrogenous manures in alternate years only. The test thus included barley as well as wheat, and both nitrate of soda and sulphate of ammonia. Unfortunately, the sulphate of ammonia plots became acid, and the barley yields dropped rapidly after 1891.

There were indications of a small residual effect of nitrate of soda on wheat. The mean yields of grain of Plot 9b were a little higher than those of Plot 4, 7·9 cwt. per acre as against 6·4 in the period 1882–1906, and 5·2 cwt. per acre as against 4·6 in the last 20 years. The long-term polynomials show a marked difference in rates of deterioration of Plots 9b and 4 in 1882–1906. Plot 9b fell much more slowly than Plot 4, and closely resembled Plots 9a and 6 in its percentage deterioration from year to year. After 1906, however, the rates of fall, both actual and percentage, were higher for Plot 9b than Plot 4.

For barley the mean yields of grain per acre of plots 9b and 4 were :—

	1882–1906.	1907–1926.
Plot 9b	13·5 cwt.	7·1 cwt.
Plot 4	9·5 ,,	5·4 ,,

Here there was a definite residual effect, at any rate in the first period. The percentage rates of deterioration of grain yields on Plots 4, 6, 9a, and 9b were all similar in the period 1882–1906; in the last 20 years they were 3·0 on Plot 9b and 2·4 on Plot 4.

With sulphate of ammonia the comparison is complicated by the acidity, and it is not clear how many years should be included. The mean yields of grain in the periods 1882–91, 1892–1901 were in cwt. per acre.

	Barley.		Wheat.	
	1882–91.	1892–1901.	1882–91.	1892–1901.
Plot 8b	16·7	9·4	11·3	13·0
Plot 4	11·1	8·6	8·5	5·1

In the first 10 years there was a definite residual effect for both crops, but particularly marked in the case of barley.

The behaviour of the plots in the second 10 years, 1892–1901, is interesting. Owing to the effects of acidity the barley Plot 8 dropped rapidly, the mean yield being little more than half what it was in the previous 10 years, and only slightly above that of Plot 4. The results for wheat were directly opposite. The mean yield of Plot 8b increased from the first period, largely owing to remarkable yields of 28 and 23 cwt. of grain per acre in 1894 and 1898 respectively; 4 on the other hand was dropping steadily throughout. The mean yield of Plot 8b (wheat) in 1902–6 was 6·1 cwt. of grain per acre; after the change of manuring in 1907 the yields fell at once well below those of Plot 4. One half of the barley plots received 2 tons lime per acre in 1897 and another 2 tons in 1912; and one half of the wheat plots had 1 ton lime per acre in 1905 and another in 1918. In both cases the first dressing raised the yields above those of Plot 4 for nearly 10 years, but the effects of the second dressings appeared to last only about 4 years.

Taking the plots as a whole, there was a marked residual effect on barley for both sulphate of ammonia and nitrate of soda of the dressings given in 1882–1906. There are also indications of a residual effect on wheat. For both crops the effects were greater for sulphate of ammonia than for nitrate of soda.

Residual Effect of Farmyard Manure.

Plots 10a and 11a received farmyard manure containing approximately 53 and 105 lb. nitrogen per acre respectively, each year from 1877 to 1881. After 1881, these plots were left without manure to see whether any residual effect of the previous dressings could be detected. This was continued until 1906, except that in 1889 Plot 10a received rape cake, containing 42 lb. nitrogen per acre, and in 1888 Plot 11a (barley) received in mistake farmyard manure containing 105 lb. nitrogen.

The mean yields of grain and average decrease in yield each year throughout the period are given in Table 57, the average decrease being also given as a percentage of the mean yield.

TABLE 57.—RESIDUAL VALUE OF FARMYARD MANURE. MEAN YIELDS OF GRAIN, 1882–1906: CWT. PER ACRE.

Plot.	Barley.			Wheat.		
	Mean Yield.	Mean Annual Decrease.	Per Cent. Annual Decrease.	Mean Yield.	Mean Annual Decrease.	Per Cent. Annual Decrease.
11a . . .	13·6	0·37	2·7	9·0	0·13	1·5
10a . . .	10·7	0·36	3·4	8·3	0·17	2·0
1 . . .	7·9	0·35	4·4	6·3	0·23	3·6
7 . . .	8·2	0·24	3·0	7·4	0·16	2·2

A striking residual effect appears for barley, and the double dressings gave double the increment over Plots 1 and 7. With wheat the effect is less marked. From the columns showing the mean annual decreases it will be seen that on the whole the increments decreased for barley and increased for wheat as time went on. Even for barley, however, the effect appeared to persist to the end of the twenty 5-year period, the mean increments of Plots 11a and 10a over the mean of 1 and 7 in the last 5 years 1902–6 being 5·0 and 2·4 cwt. of grain per acre respectively.

Since the farmyard manure was applied for 5 years only, the size and long continuance of the increments are remarkable. The effects may be due to soil heterogeneity. The wheat and barley Plots 10 and 11 adjoin, and the facts would be explained if the fertility of the wheat and barley fields increases as we proceed from the opposite sides of the fields, which contained Plots 1, 4, and 7, towards the adjoining sides, especially if the difference in fertility were greater on the barley than on the wheat field, since the apparent residual effect of farmyard manure was greater for barley than for wheat. While no crucial test of this

supposition can be made, we can examine it in the light of the manurial comparisons and see whether it leads to inconsistent or improbable conclusions. The gradient would account, in part at least, for the apparent residual effects of nitrate of soda and sulphate of ammonia, and for the observation that the residual effect of nitrate of soda, where there was no complication from acidity, was greater for barley than for wheat. Against it, however, is the fact that sulphate of ammonia gave at first larger residual effects than nitrate of soda.

The gradient would cause an over-estimation of the average direct effects of nitrate of soda, sulphate of ammonia, rape cake and farmyard manure on differences between the yields of their respective plots and Plots 1, 4, and 7, the over-estimation being greatest for farmyard manure, and greater for nitrate of soda than for sulphate of ammonia: with the further consequence that the effectiveness of farmyard manure relative to nitrate of soda, and that of nitrate of soda relative to sulphate of ammonia, had been exaggerated. All this is quite possible. The effects of soil heterogeneity would probably be most marked in the early years of the experiment. As time went on, the continuous applications of one type of manure to each plot would exert a predominating influence on the soil.

Two pairs of plots were placed differently with respect to the gradient for wheat and barley. If the effect of rape cake (Plot 10b) is measured as the difference in mean yields of Plots 10b and 10a, which is quite reasonable since 10a was unmanured from 1882 until 1906 and had the same treatment as 10b previous to 1882, then the difference 10b-10a is in the direction of the gradient for wheat and in the opposite direction for barley. The comparison is best made on total produce, as wheat grain yields were generally smaller, and straw yields higher than barley. The mean yields of total produce of 10b and 10a in 1882–1906 were in cwt. per acre :—

	Barley.	Wheat.
10b (rape cake)	38·2	39·7
10a (unmanured) . . .	19·2	19·4
Difference	19·0	20·3

The comparison is unfair after 1906, as the subsequent fall in barley yields may have been due to acidity.

Similarly, we may measure the effect of farmyard manure in the period 1882–1906 as the difference between Plot 11b (farmyard manure) and 11a (unmanured 1882–1906). The mean yields of total produce were in cwt. per acre :—

	Barley.	Wheat.
11b (farmyard manure) . .	41·3	42·6
11a (unmanured) . . .	29·6	24·2
Difference	11·7	18·4

which is what we should expect from the gradient.

Thus the conclusions reached above (p. 156), that rape cake was more effective for wheat than for barley and (p. 159) that the residual effect of farmyard manure was greater for barley than for wheat, both fit in well with a gradient of this type. In the period 1907–26, the difference 11b-11a represents the difference between the effect of farmyard manure and that of the dressing potash and nitrate of soda. This difference was slightly greater for barley than wheat, the mean difference being 8·4 cwt. of total produce per acre (barley) and 7·9 cwt. (wheat).

On the whole, such a fertility gradient, besides accounting for the residual effect, does not seem improbable when viewed from its effect on the other manurial comparisons. The outstanding weakness of unreplicated experiments is that their verdict on any comparison is always open to the challenge that part or all of it represents fertility difference in different parts of the field. In considering the residual effects considered above, it should be remembered that they can be explained, in part at any rate, by a simple hypothesis about the fertility distribution which appears quite consistent with the observed facts.

CHAPTER XI.

EFFECT OF WEATHER CONDITIONS ON YIELD OF WHEAT AND BARLEY.

In the last chapter the effects of the different manures over the 50 years available were represented by smooth curves, polynomials of the fifth degree, fitted to the data for yield. In this chapter the deviations of the annual yields from these polynomials are discussed, so as to bring out the influence on yield of factors which fluctuate in a random manner from year to year but show no permanent change with time.

Inspection of the deviations shows that high correlations exist between almost all plots—not merely between those with the same crop or the same manurial treatment—so that seasons favourable to barley were also favourable to wheat. Generally, however, the agreement between plots of the same crop is better than that between plots of different crops, and for each crop those plots receiving the same type of manurial treatment, such as 3, 6, and 9 for instance, are more highly correlated than plots receiving different types. The latter point has an important bearing on the rainfall effect, and will be discussed more fully later (cf. p. 168).

Table 58 shows the estimated variance (i.e. the square of the standard deviation or standard error) due to annual causes on corresponding wheat and barley plots. This is found by dividing the sum of the squares of the deviations from the curves by the appropriate number of degrees of freedom, which in this case is 24. The percentage standard deviation is 10 times the square root of the percentage variance.

TABLE 58.—VARIANCE DUE TO ANNUAL CAUSES. WHEAT AND BARLEY. WOBURN.

Plot.	Barley, Grain, cwt. per Acre.			Wheat, Grain, cwt. per Acre.		
	Mean Yield.	Variance.	Per Cent. Variance.	Mean Yield.	Variance.	Per Cent. Variance.
1 . .	8·7	8·2	10·9	6·6	4·9	11·1
7 . .	8·5	7·9	10·8	7·4	6·2	11·3
4 . .	9·6	13·5	14·7	6·7	3·8	8·5
2 . .	11·1	8·8	7·1	9·8	25·3	26·3
3 . .	14·7	18·9	8·8	11·2	22·3	17·7
5 . .	13·3	18·1	10·2	14·8	32·5	14·9
6 . .	19·1	19·3	5·3	15·0	19·3	8·6
8 . .	16·5	21·6	7·9	17·0	37·8	13·0
9 . .	22·1	21·9	4·5	16·9	18·4	6·4
11b . .	18·0	20·7	6·4	13·7	17·0	9·1

The yields are in cwt. per acre, and the fourth and seventh columns show the variance expressed as a percentage of the square of the mean yield, this being a better index of variability than the actual variance. The actual variances are higher for barley than for wheat, except on the plots receiving nitrate of soda or sulphate of ammonia, but the percentage variances are smaller, except on Plot 4. On the latter standard, wheat was more variable than barley at Woburn. At Rothamsted W. A. Mackenzie found that the percentage variance was higher for barley than wheat. Her comparison was restricted to four plots, receiving no manure, minerals only, minerals and ammonium salts, and farmyard manure respectively, and the comparable plots were on different fields. On the other hand, the numbers of years over which the comparison extended were 67 and 70 at Rothamsted, as against 30 at Woburn.

The effect of manurial treatment on percentage variability was somewhat different for wheat and barley. With barley, nitrate of soda and sulphate of ammonia reduced the variability both in presence and absence of minerals, the double dressings giving a further reduction. Minerals increased the variability in the absence of nitrogen and with sulphate of

ammonia, but reduced it with nitrate of soda. With wheat, on the other hand, the presence of minerals reduced the variability, and in the absence of minerals nitrate of soda and sulphate of ammonia both increased it. In the presence of minerals the single dressing of nitrogen did not reduce variability, but the plots with the double dressing were less variable than those with the single. The same differences between the two crops appeared in the Rothamsted experiments, except that with barley the complete minerals reduced variability in presence of sulphate of ammonia.

For both wheat and barley at Woburn the percentage variance was low on the farmyard manure plot, and lowest of all on the plot receiving minerals and the double dressing of nitrate of soda.

The Curves Showing the Effect of Rainfall on Yield.

The linear regressions of the deviations of the annual yields from the polynomials on the rainfall throughout the year were found by R. A. Fisher's method [1] for Plots 1, 7, 4, 2, 5, 8, 3, 6, 9, and 11b. Curves were drawn from these showing the change in yield of wheat and of barley to be expected from an inch of rain above the average at any time of the year. The curves for Plots 3, 5, 7, 9, and 11b are shown in Figs. 11–13, for barley and 18–20 for wheat, the curves for Plots 4a and 6 (minerals plus ammonium salts) at Rothamsted being included for comparison.

In finding the effect of an inch of rain above during a short period, such as a week, it is sufficiently accurate to take the reading at the point on the curve vertically above the mid-point of the period. Longer periods must be divided into a number of equal periods, each of length not greater than a week, and the readings at the mid-point of each of these small periods must be averaged. For these longer periods the effect is better described as "average rainfall

[1] *Phil. Trans.*, B, 213, 1924.

effect" than simply "rainfall effect," because it depends upon both the total rainfall and its distribution throughout the period. The total effect of the actual rainfall on yield during a period is obtained by finding the difference in inches between the rainfall in each week of the period and the 30-years' average for that week, multiplying this by reading on the curve above the mid-point of the week, and adding

Smooth curves representing the linear effects of rainfall on yields of Barley grain.

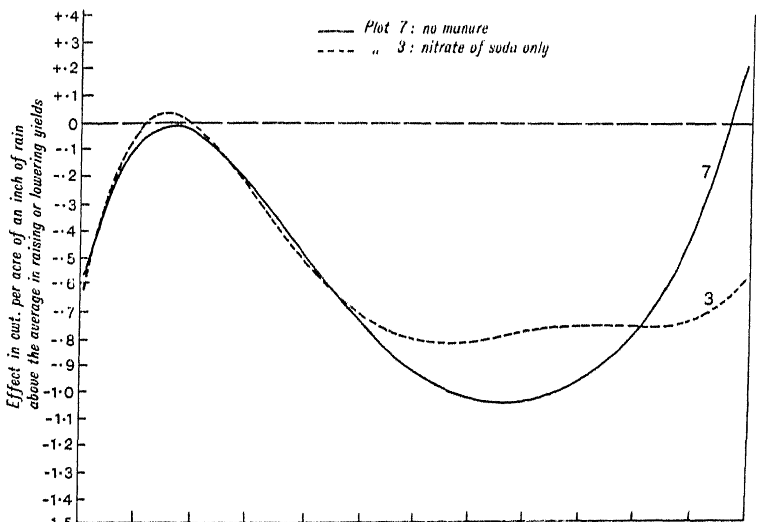


FIG. 11.—Barley grain.
Plots 3: nitrate of soda only.
7: no manure.

for all weeks of the period—taking into account the signs of the differences and of the readings.

In fitting the curves account was taken only of that part of the rainfall effect which is directly proportional to the amount by which the rainfall differs from the average, i.e. the linear effect. The effect of rainfall on yield is certainly not linear over the whole range of variation of rainfall, great excess or prolonged shortage of rain being alike

detrimental. The small number of years available at Woburn did not, however, justify the inclusion of quadratic terms in the application of Fisher's method. The importance of these terms in the case of March-April rainfall was studied, however, as described later (cf. p. 174).

On none of the twenty plots examined was the regression function significant, and the only significant regression

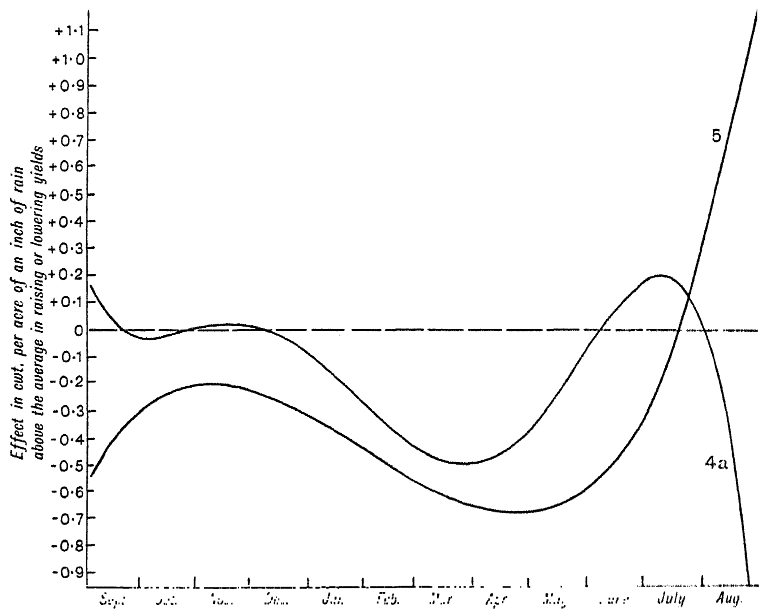


FIG. 12.—Barley grain.

Plots 5 : minerals plus ammonium salts (Woburn).
4a : minerals plus ammonium salts (Rothamsted).

coefficients were those representing the effect of the mean annual rainfall, but not of its distribution, on Plots 1, 7, and 4 (barley). Also none of the regression functions for the 50-year period 1877–1926 for the three plots with unaltered manures, 1, 7, and 3a, was significant. In view of the lack of significance much time was spent in investigating the effect of particular rainfall variates. As these investigations

differed for wheat and barley, and as the rainfall curves are dissimilar, the crops will be considered separately.

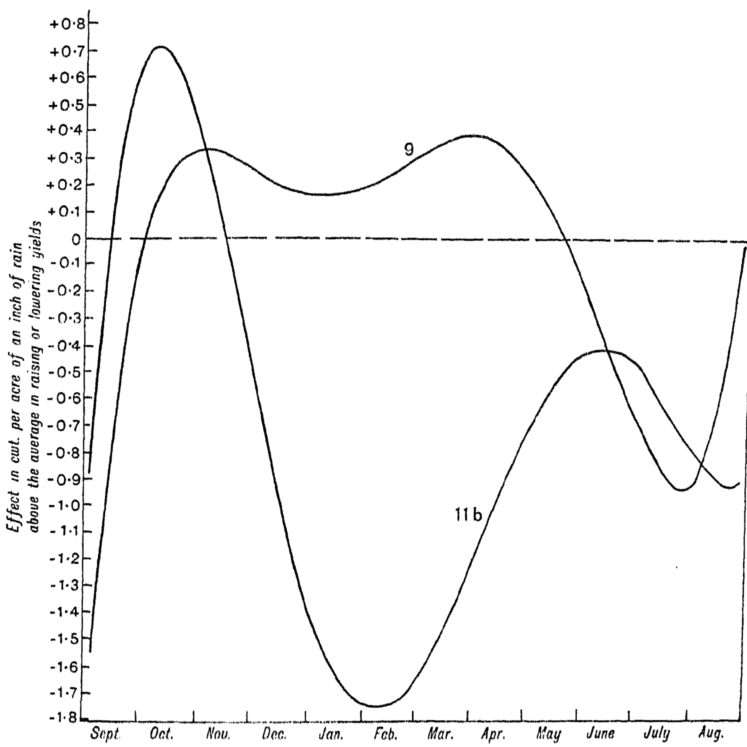


FIG. 13.—Barley grain.
Plots 9: minerals plus nitrate of soda.
11b: farmyard manure.

The Effect of Rainfall on Barley Yields.

Considered from the point of view of shape and position in relation to the zero line of the vertical scale, the curves arrange themselves into groups which correspond roughly with the manurial treatments which the plots receive. The grouping appears to be: 1, 4, and 7; 3 and 6; 2 and 5; 8 and 9; and 11b. Only one of the differences between pairs of curves belonging to different manurial groups was tested for significance: the plots chosen were 6 and 4, where

most difference might be expected, but the difference of effect of rainfall showed no sign of significance. It is improbable, therefore, that the differences between other pairs of plots are significant.

It has been noted above that the deviations from the polynomials of plots in the same manurial groups are more closely associated than those of plots in different manurial groups. This indicates that there is some important meteorological factor, or combination of meteorological factors, which acts differently on plots receiving different types of manuring. Since neither the 12 months' rainfall curves nor the differences between pairs of curves are significant, the grouping of the rainfall curves may be simply a reflection of the grouping of the deviations from which they were obtained. It was found later that the combination of the following factors significantly affected yields: total rainfall in March-April, its square and cube, and rainfall 60–90 days after sowing and its square (cf. p. 174). An investigation was therefore made for Plots 1, 4, 7, 3, 6, and 11b to see whether the yields of plots receiving the same type of manuring remained more highly correlated than those of plots receiving different types, after taking account of the significant effects of these rainfall factors. Six significant differences in degree of association were tested. Of these, two were reduced below significance level by the rainfall effect, but the other four remained significantly different. The investigation as a whole therefore points to the influence of some undiscovered meteorological factors which exert a different effect on plots having different types of manure.[1]

If the 30- and 50-years' rainfall curves for Plots 1, 7, and 3a were similar in shape and position with regard to the zero line, there would be more grounds for supposing that the shapes of the curves were reliable. The similarity is, however, very rough. All three pairs of curves agree in showing that rainfall above the average is harmful at almost all periods

[1] See W. G. Cochran, *J. Agr. Sci.*, vol. 25, part 4, 1935, pp. 510–22.

of the year, but the times of year and intensities of the maximum effects differ considerably for numbers of the same pair. The times and intensities of the periods of maximum damage are given below for comparison.

	Time of Maximum.	Decrease in Yield of Grain Due to an Inch of Rain over the Average (cwt. per Acre).
Plot 1	(30 years), Feb. 25–March 2	1·1
	(50 years), April 10–15	0·6
Plot 7	(30 years), April 16–21	0·9
	(50 years), April 17–22	0·6
Plot 3a	(30 years), March 17–22	0·7
	(50 years), Feb. 22–27	0·4

A brief summary of the rainfall curves is given below, though the readings lack statistical significance.

On all curves the average annual rainfall at Woburn (24 inches) is indicated as sufficient for the needs of the plants; additional rainfall is generally harmful. The curves may be grouped as follows:—

(*a*) The plots receiving no nitrogenous manure—1, 7, and 4. Rainfall above the average is harmful from January until May, the period of maximum damage occurring in the months February, March, and April. Winter rain has not much effect.

(*b*) Plots 3 and 6. Additional rainfall is harmful from January until harvest; on Plot 3 the damage is uniform throughout the period, whereas 6 has two periods of maximum damage, one in January and one in July.

(*c*) Plots 2 and 5. These are similar in shape, Plot 2 lying above Plot 5 most of the year. The period of maximum damage is later than on Plots 1, 7, and 4, and the depression of yield itself is less.

(*d*) Plots 8 and 9 are similar in shape, though 9 lies higher most of the year. Rainfall has little effect from October to May, and an excess seems beneficial on Plot 9 in that period. The only period of damage is in July.

(*e*) The farmyard manure Plot 11b must be classed by itself. Alone of all the barley plots it shows a period of

marked benefit, which occurs in October. From the beginning of December until harvest, rainfall above the average is harmful, and the maximum damage in the months January to March is much greater than on any other plot. The curve rises from March until the middle of June and then falls again.

A similar study was made by J. Wishart and W. A. Mackenzie [1] on the effects of rainfall on thirteen barley plots on Hoos Field at Rothamsted over the years 1854–1921, omitting 1912 and 1913. The comparable plots on Stackyard and Hoos are: 1 and 7 with 1–0 and 6–1; 2 with 1–a; 4 with 4–0; 5 with 4–a; and 11b with 7–2. Since, however, none of the regressions on rainfall at Hoos was significant, the same unreliability attaches to the Rothamsted as to the Woburn curves, and detailed comparison cannot be made. There is a remarkable similarity in shape between the 50-year, though not the 30-year, curves for Plots 1 and 7 and those for 1–0 and 6–1. The four curves 1 (50 years), 7 (50 years), 6–1 and 1–0 have each four turning values, two maxima and two minima, except that the last maximum of 1–0 is flattened out. The close similarity in shape is shown in Table 59, which gives the positions and rainfall effects at

TABLE 59.—COMPARISON OF HOOS FIELD, ROTHAMSTED, PLOTS 6–1 AND 1–0 WITH WOBURN PLOTS 1 AND 7.

Plot.	1st Minimum.		1st Maximum.		2nd Minimum.		2nd Maximum.	
	Date.	Change in Yield.	Date.	Change in Yield.	Date.	Change in Yield.	Date.	Change in Yield.
6–1	Oct. 9–14	−0·4	Dec. 9–14	−0·2	April 4–9	−0·8	July 29–Aug. 3	0·4
1–0	Oct. 21–26	−0·4	Dec. 14–19	−0·3	April 17–22	−0·7	—	—
1	Oct. 28–Nov. 2	−0·6	Dec. 12–17	−0·5	April 10–15	−1·2	Aug. 2–7	0·4
7	Oct. 16–21	−0·4	Dec. 12–17	−0·2	April 17–22	−1·2	Aug. 14–19	0·4

[1] *J. Agr. Sci.*, vol. 20, part 3, 1930, pp. 418–39.

the turning values. The table shows in alternate columns the dates of the turning values and the changes in yield (in bushels per acre) expected from an inch of rainfall above the average in the corresponding period.

For the other comparable plots there is no such exact agreement. But taking the set of comparable plots as a whole, and assuming that the curves represent rainfall effects, there are no definite signs that these effects on the barley yields have differed at the two places. The conclusion is, of course, based on rough general comparisons only; detailed comparison reveals considerable differences.

Effect of Rainfall during the Six Months in which Barley is in the Ground.

It seems reasonable to suppose that the course of the rainfall is of more importance to the crop when the barley is growing than when it is not, though, to judge from the rainfall curves for the whole year, there appears to be little difference between the linear effects of rainfall in the periods September to February and March to August. The linear regressions of the yields of Plots 1, 7, 4, 2, 5, 8, 3, 6, 9, and 11b on the rainfall from the middle of February until the end of August were worked out by the same method as the regressions on the whole year's rainfall, and give likewise curves showing the change in yield expected from an inch of rain above the average at any period during the 6 months. Again none of the regressions was significant.

The 6-months curves' for the different plots are much more similar in shape than the 12-months' curves. They all show a minimum centred round March and April, a maximum in June, and a further minimum, fairly sharp, at the beginning of August. As in the 12-months' curves, the farmyard manure plot shows more violent fluctuations in rainfall effect than any of the other plots. The difference in shape of the 6- and 12-months' curves in the months February to August is not a contradiction, since the former reproduce

the fluctuations in effect during the 6 months in greater detail than the latter, and take no account of the effect of

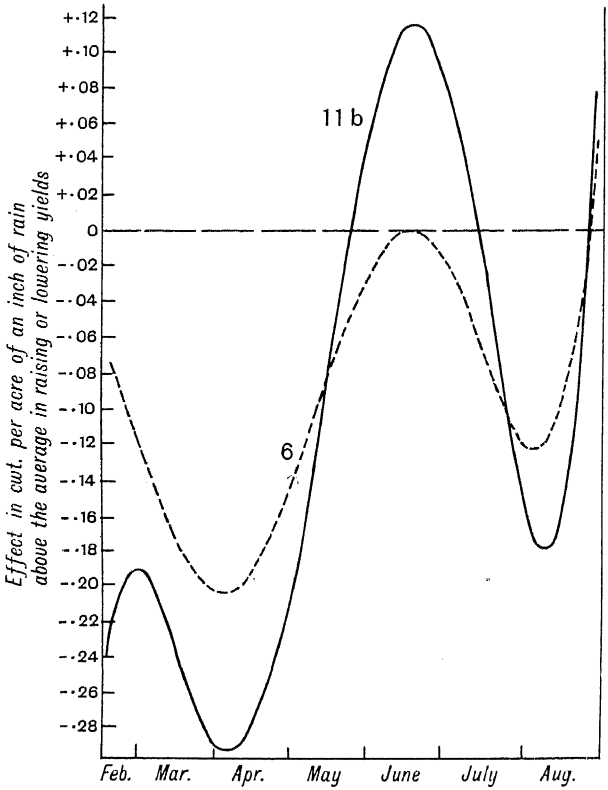


FIG. 14.—Barley grain.
Plots 6: minerals plus nitrate of soda.
11b: farmyard manure.

winter rain. The curves for Plots 6 and 11b are given in Fig. 14.

Other Investigations on the Effect of Rainfall on Barley Yields.

The usual method of approach having given no significant results, a search was made to find particular meteorological factors which might affect yield significantly.

When working out multiple regressions on a large number of selected meteorological factors, with the object of picking out the most highly significant regression coefficients, caution is necessary in interpreting the results. For in a short period, such as 30 years, it is quite possible that one of the selected factors may happen to vary in the same way as yield, when there is no causal connection between the factor and the yield. In fact, where the largest of the regression coefficients is picked out, the ordinary test of significance does not apply, but a much more stringent test devised for the largest of a number of deviations. The multiple linear regressions of the yields of Plots 5, 6, 7, and 11b on ten selected factors were worked out. A cubic curve was fitted to the yields of grain in the period 1877–1906 and the deviations were correlated with the weather variates. The factors were: rainfall in September-February, March-April, May-June, July-August; mean temperature in March-April, May-June, July-August; drought in March-April, May-June, and July-August. The "drought" in a given period was measured by a conventional scale obtained from the number of 6-day intervals in the period in which less than ·05 inch of rain fell. The numbers of marks given to 1, 2, 3 . . . 7 dry 6-day periods were 1, 2, 4, 7, 10, 14, and 18 respectively. Neither the regression as a whole, nor any individual regression coefficient was significant, the March-April rainfall coefficient alone approaching the 5 per cent level of significance. The drought coefficients were all negative, indicating, as was to be expected, that long periods of dry weather in summer depress yield.

Two factors possibly concerned in the apparent absence of rainfall effect were studied.

(1) The effect of rain falling at a particular time on the crop would depend on the stage of growth of the plant rather than on the particular calendar date on which the rain fell. In the absence of a more accurate method, the stage of growth of the plant was measured by the number of days

after sowing. The sowing date varied between February 26 and April 17 in 1901.

(2) Examination was made to see if the linear part of rainfall effect were relatively unimportant, as would probably happen, for instance, if the average rainfall at Woburn were the optimum rainfall for the crop; in that event rainfall above or below the average would both decrease yields. This second point can be tested by taking a regression on the square and higher powers of the rainfall as well as on the rainfall itself.

The weather variates chosen were :—

Rainfall during 30 days before sowing.
,, ,, 30 ,, after ,,
,, ,, 30–60 days after sowing and its square.
,, ,, 60–90 ,, ,, ,, ,, ,, ,,
March–April rainfall and its square and cube.
Sowing date (measured as the number of days from February 26—the earliest sowing date in the 30 years).

The regressions of the yields of Plots 4, 6, and 11b on these factors, in various combinations, were worked out for the period 1878–1906. The first year—1877—was omitted on the grounds that, as the barley in that year had followed a rotation crop, it was not strictly comparable with later crops which followed a previous barley crop. The yields were divided into five periods: 1878–82, 1883–8, 1889–94, 1895–1900, 1901–6, and the deviations from the means of the periods were used to represent that part of yield due to annual causes only. Of the variates chosen the only two which appeared to have any effect on yield were rainfall during March-April and rainfall 60–90 days after sowing. The multiple regression of the yields of the ten principal plots were worked out on March-April rainfall, its square and cube, and rainfall 60–90 days after sowing and its square. The regressions were significant at the 5 per cent point on plots 3, 4, 5, 6, and 7, and at the 1 per cent. point on Plot 8. The quadratic and cubic terms were more important than the linear term. An investigation was made of the effect

of rainfall 60–90 days after sowing and its square, after taking account of the effect of March-April rain and its square and cube, and vice versa. In neither case was the additional reduction in variance significant. It is therefore not possible from these results to say whether the significance is due to March-April rainfall, rainfall 60–90 days after sowing, or a combination of these factors.

The curves in Figs. 18, 19, which have been drawn from the regression equations, show the change in yield of grain expected when the rainfall in March-April differs from the average by any known amount after eliminating the effect of rainfall 60–90 days after sowing. The horizontal scale shows March-April rainfall in inches, measured from its mean value 3·0 inches, and the vertical scale the changes in yield of grain in bushels per acre.

All curves show that the average March-April rainfall was too high ; the most suitable rainfall appears to have been between 1·5 and 2·0 inches. The positions of the maxima on the curves are not accurately determined, because only twice in the 29 years was the rainfall below 1·5 inches, so that the shapes of the curves near the ends are determined by a few values only. The rise in expected yield when the rainfall exceeds 4 inches is not considered to be a true effect of March-April rainfall.

The increments in yield in years of dry March-April are about the same on the no-manure, sulphate of ammonia, and farmyard manure plots ; the nitrate of soda and minerals only plots did better than the others. In years of moderately wet springs, the sulphate of ammonia and no-manure plots showed about the same decrease in yield, the nitrate of soda, minerals only, and farmyard manure plots showing a greater decrease. In particular, the amount by which nitrate of soda exceeded sulphate of ammonia was greater in years of dry March-April than in years of wet.

The conclusion that dry springs are more favourable to nitrate of soda than to the other manures is in contradiction

with the results of the 12-months' rainfall curves, which indicated, for what they are worth, that the addition of nitrate of soda mitigated the harmful effect of spring rainfall,

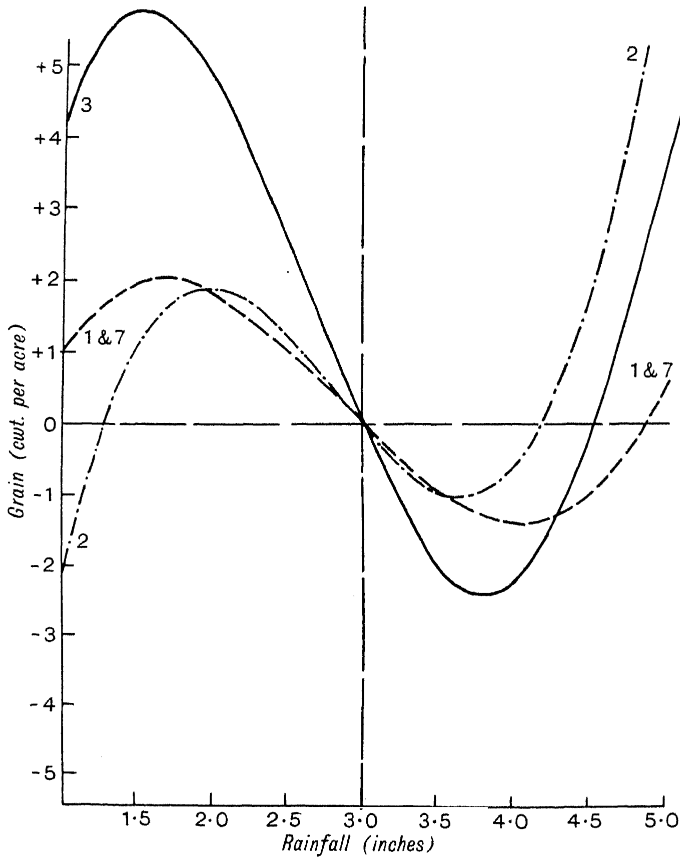


FIG. 15.
Plots 1 and 7: no manure.
2: ammonium salts only.
3: nitrate of soda only.

i.e. that as compared with plots receiving no nitrogen the nitrate of soda plots yielded relatively better in years of wet spring and worse in years of dry spring (cf. Figs. 11 and 13). The difference is introduced by the quadratic and cubic terms

in the regression, for if we restrict ourselves to the linear term in the March-April rainfall regression, it gives the same

Curves showing the linear and simpler non-linear (cubic) effects of rainfall during March and April on yield of barley grain.

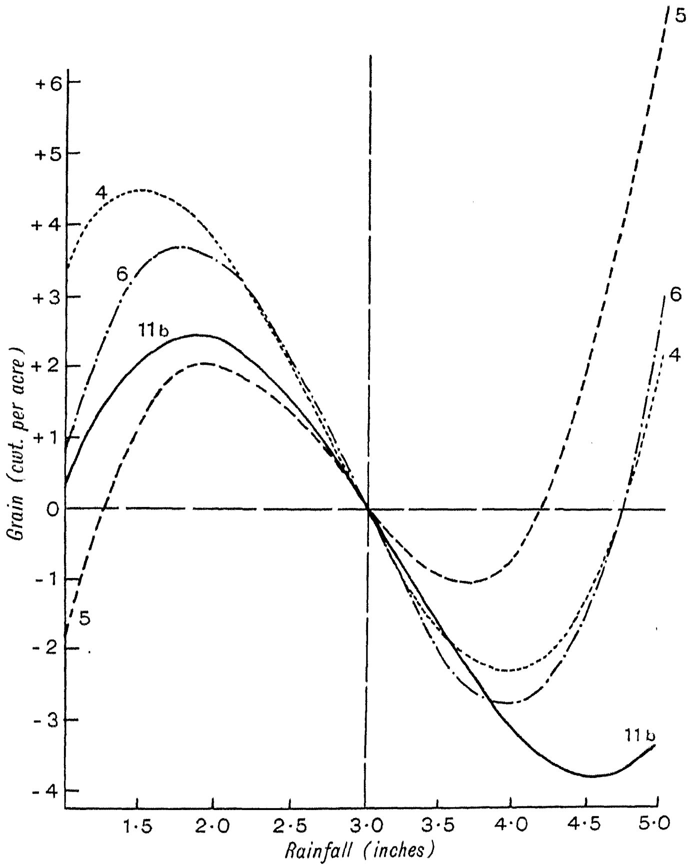


FIG. 16.

Plots 4 : minerals only.
5 : minerals plus ammonium salts.
6 : minerals plus nitrate of soda.
11b : farmyard manure.

conclusion as the 12-months' curves. In view of the importance of the quadratic and cubic terms, the conclusion

that dry springs are not favourable to nitrate of soda is doubtful.

Similar curves have been drawn for the rainfall 60–90 days after sowing, after eliminating the effect of March-April rainfall. This period was variable on the calendar date, but represents the effect of early summer rainfall, the average

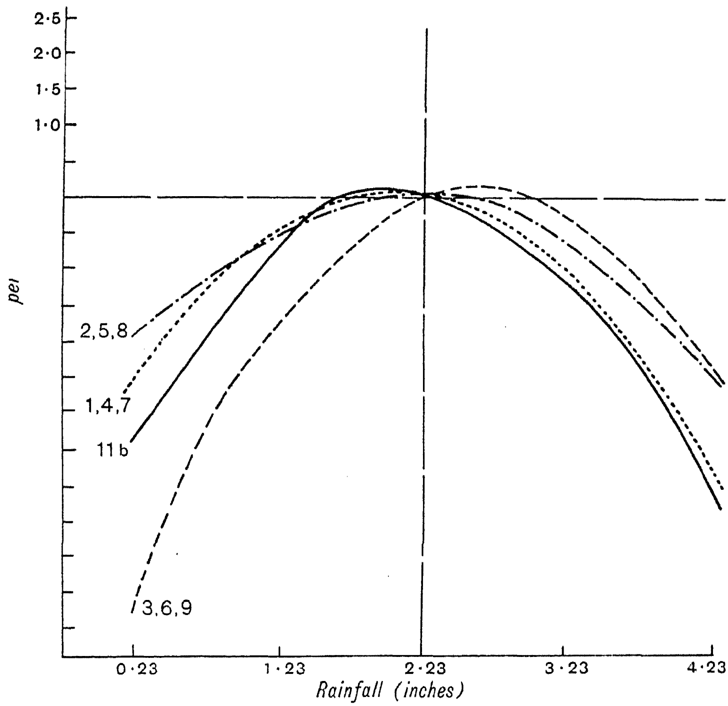


FIG. 17.—Effect of rainfall 60–90 days after sowing on yields of barley grain.

Plots 1, 4, 7: no nitrogen.
2, 5, 8: ammonium salts.
3, 6, 9: nitrate of soda.
11b: farmyard manure.

interval being from May 24 to June 22 inclusive. The curves are shown in Fig. 17. The actual average rainfall, 2·23 inches, was very near the optimum for most plots, 8 and 9 being the only plots which do better when rainfall is slightly

above the average. There is very little difference between the sulphate of ammonia, no-nitrogen, and farmyard manure plots ; but the nitrate of soda plots appear to increase more when the rainfall is above the average and decrease more when it is below.

It was confidently expected that on the light, sandy soil of Woburn the amount and distribution throughout the year of the rainfall would exert a considerable effect on barley yields. As the above report shows, a great deal of labour devoted to investigating the question has led to very meagre results. This must not be taken as showing that the original expectation is disproved, but merely as pointing to the complex nature of the rainfall effect. The fact that deviations from the significant curves for March-April rainfall and rainfall 60–90 days after sowing still group themselves according to the type of manuring which the corresponding plots received, points, as has been said, to some important but yet undiscovered meteorological factor. It seems unlikely, however, that much progress will be made towards elucidating the factors involved by statistical analysis of the present type alone. For until some well-founded hypothesis is forthcoming as to the particular combination of factors which is of importance, further statistical analysis must consist simply of a search for likely factors. The dangers of this method have already been pointed out, and in view of the relatively small number of years available at Woburn it is likely to prove fruitless. If and when new hypotheses arise as to the influence of weather on crops, the data will be available for putting them to the test.

The Effect of Rainfall on Wheat Yields.

The curves (cf. Figs. 18–20) showing the effect of rainfall throughout the year on the wheat yields of the different plots agree in shape more closely than the barley curves. With the exception of 11b, which, as for barley, is unique, all the curves have a minimum in September or October, a

maximum centred round January, and a further minimum in May or June. The same unreliability attaches to the wheat curves as to the barley, none of the wheat curves being significant. Rainfall curves were also fitted to Plots 1, 7, and 3a over the 50 years 1877–1926. On Plots 1 and 7, while the rainfall effects are much smaller in magnitude on the 50-year

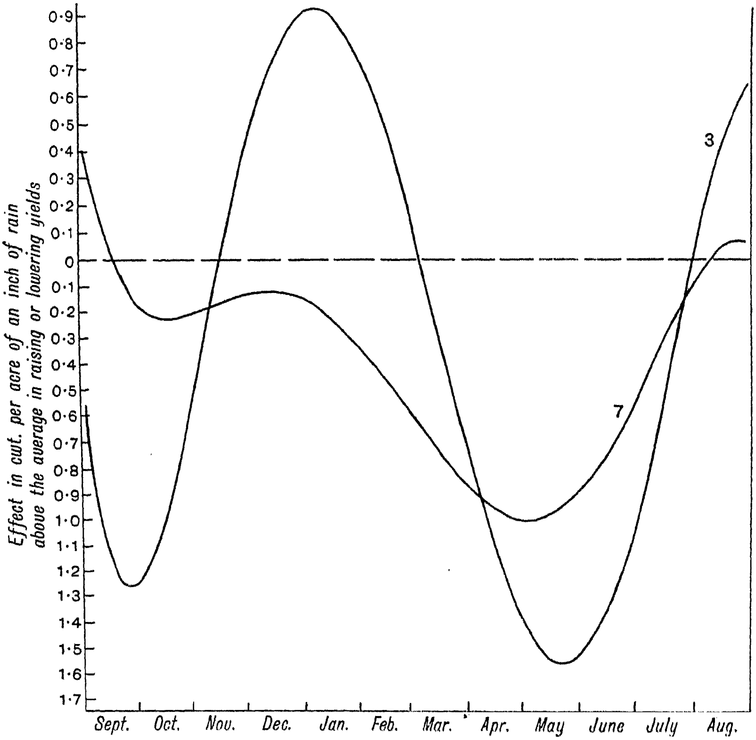


FIG. 18.—Wheat grain.
Plots 7: no manure.
3: nitrate of soda only.

curves, the general shapes of the 30- and 50-year curves agree quite well; but on Plot 3a the agreement is very bad.

The main features of the 30-year curves are as follows:—

(*a*) Plots 1, 7, and 4. The only time of year when the effect of rainfall is at all pronounced is in the months April-June, when additional rainfall is harmful.

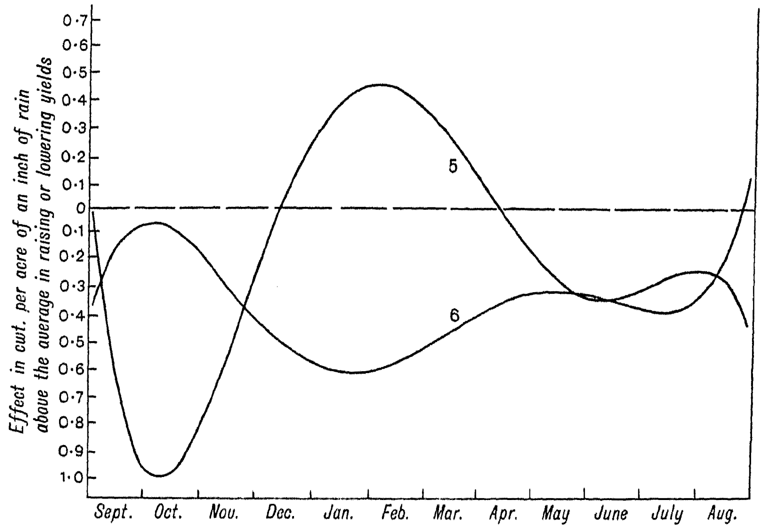


FIG. 19.—Wheat grain.

Plots 5: minerals plus ammonium salts (Woburn).
6: minerals plus ammonium salts (Rothamsted).

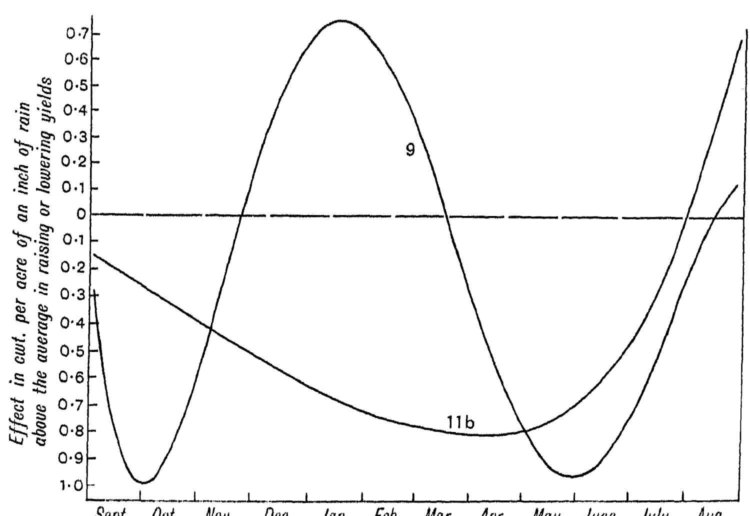


FIG. 20.—Wheat grain.

Plots 9: minerals plus nitrate of soda.
11b: farmyard manure.

(*b*) Plots 3, 6, and 9. The curves are closely similar, except that on 6 and 9 the fluctuations in rainfall effect are less pronounced than on 3. There is a period of damage from rainfall above the average in September-October; a period of benefit in January; and a further period of damage in May-June.

(*c*) Plots 2, 5, and 8. As regards shape, 2 should be classed with 3, 6, and 9; on Plot 5 the only marked effect is a period of damage in October; Plot 8 shows a period of benefit in March and April, and differs from all the other plots in that, taking the year as a whole, rainfall above the average is beneficial to yields.

(*d*) On Plot 11b, additional rainfall is harmful at all times of the year. The effect slowly increases in magnitude from September until April, after which it decreases more rapidly.

In marked contrast with these Woburn curves, those obtained by the same method for the Broadbalk plots at Rothamsted in the period 1854–1918 were definitely significant, and told a consistent and intelligible story.

The Rothamsted curves have all four turning values, a maximum in October, a minimum in January, a further maximum in April or May, and a further minimum in July, except that the last is missing on the curve for the farmyard manure Plot 2b. When classed according to the intensities of these turning-points in rainfall effect, the curves group themselves according to the type of manuring they receive. There were thirteen plots in all, and the system of manuring was graded from plots with no nitrogenous manures through plots with complete mineral salts and increasing amounts of ammonium salts to plots in which the manuring was highly unbalanced owing to mineral deficiency. The farmyard manure plot must be classed by itself.

The turning value in October is a period of damage of 0·2 bushels per acre on the plots with no or insufficient nitrogen, but a period of benefit of from 0·2 to 0·4 bushel per

acre on the plots with sufficient or excess nitrogen. The damage due to excess rainfall in January is small—about 0·3 bushel per acre—on the plots with no nitrogen, but increases to 1·8 bushel per acre on the plots receiving complete minerals and ammonium salts. On the plots which cannot make use of all the nitrogen supplied owing to lack of minerals, the damage is less, being about 0·9 bushel per acre on Plots 10 and 11 which have the greatest excess of nitrogen. There is a period of minimum damage in May of roughly the same intensity, 0·3 bushel per acre, on all plots except 10 and 11, on which rainfall above the average is beneficial at that time of the year. Lastly, the intensity of the damage in July increases steadily throughout the scale from 0·6 bushel per acre on the plots with no added nitrogen to 1·7 bushel per acre on Plot 10.

It will be seen that these curves do not agree at all with those at Woburn, the common features of the latter being, as pointed out above, a minimum in September or October, a maximum in January, and a further minimum in May or June.

The only Woburn curve which exhibits the general features of the Broadbalk curves is the 30-years' curve for Plot 3a, though there is no plot on Broadbalk which received nitrate of soda only. No conclusion can be drawn, however, from the differences between the Woburn and Rothamsted curves in view of the unreliability of the former.

No connection was found between sowing date and yield.

To examine the influence of non-linear effects, the regressions of the yields of all plots on March-April rainfall, its square and its cube were worked out by the method used for barley. The regressions were significant only for Plots 3 and 6. It is interesting, however, that the linear term in the regression was unimportant compared with the quadratic and cubic terms. In Plot 3, for instance, the sum of squares of deviations from the 6-year means (24 d.f.) was 1827·27,

and the reductions in this on fitting successively the linear, quadratic, and cubic terms in the regression were 43·07, 309·49, and 204·04 respectively. In view of their lack of significance the curves are not reproduced here. They indicate, as with barley, that the average March-April rainfall was too high, the most favourable value being about 2 inches in the 2 months.

CHAPTER XII.

THE NITROGEN CONTENT OF BARLEY AND WHEAT GRAIN.

Barley. Effects of Manuring.

THE nitrogen content of the dried barley grain was found for most of the plots for each year, with a few exceptions, from 1885 to 1926. The figures are shown in Table 114.

The principal manurial effects were a consistent increase due to nitrate of soda or sulphate of ammonia and a decrease due to minerals, as is shown in Table 60.

TABLE 60.—MEAN NITROGEN CONTENT OF BARLEY—PERCENTAGE ON GRAIN DRIED AT 100° C.

	No Minerals.	Minerals.	
No nitrogen . .	(1) 1·83	(4) 1·74	No manure (7) 1·82
Sulphate of ammonia	(2) 2·00	(5) 1·92	Rape cake (10b) 1·94
Nitrate of soda .	(3) 1·99	(6) 1·84	Farmyard manure (11b) 1·83
		(9) 2·04	Residual nitrate of soda (9) 1·81

Plot 3b was used from 1907 to 1926 to be comparable with Plot 2.

Within each of the periods 1883–1906, 1907–26 the percentages showed no tendency either to rise or fall, and throughout the experiment the only changes in mean level were those which followed the reduction of manures in 1907. Table 61 shows the mean percentages in the two periods 1883–1906, 1907–26.

On Plots 4 (minerals) and 9b (minerals + residual nitrate of soda) the percentages rose after 1906, as was to be expected

TABLE 61.—MEAN NITROGEN CONTENT OF BARLEY, 1883–1906 AND 1907–1926.

Mean Percentages.	4 (Minerals).	9b (Minerals + Residual Nitrate of Soda).	2 (Sulphate of Ammonia).	3b (Nitrate of Soda).	10b (Rape Cake).	11b (Farmyard Manure).
1883–1906	1·70	1·78	2·08	2·06	1·97	1·83
1907–1926	1·78	1·83	1·89	1·96	1·90	1·84
Mean Percentages.	**5a (Minerals + 1 Sulphate of Ammonia).**	**6 (Minerals + 1 Nitrate of Soda).**	**9a (Minerals + 2 Nitrate of Soda).**	**1 (No Manure).**	**7 (No Manure).**	**3a (Nitrate of Soda).**
1883–1906	1·97	1·83	2·15	1·85	1·82	2·06
1907–1926	1·87	1·84	1·92	1·80	1·83	2·04

from the reduction in minerals. On Plots 2 and 3, which received only nitrogenous manures, the percentages fell after 1906. Plots 5a, 6, 9a, and 10b had artificial manures supplying both minerals and nitrogen, and on these the percentages fell after 1906 except on Plot 6, on which they remained constant. They also remained about the same on the farmyard manure plot, though here the reduction in manuring was not great. Finally, on Plots 1, 7, and 3a, on which there was no change in manuring in 1907, the percentages remained about the same. The differences between the means of the two periods were significant in two cases only—Plot 2 and Plot 9a.

The acidity of the sulphate of ammonia plots had no marked effect on the percentages. In the period 1897–1906, in which the yields on Plot 2 fell practically to zero, the percentages remained high, the average being 2·16. It is not clear whether the liming had any effect. Comparison is possible on three pairs of plots—2a, 2b; 5a, 5b; 4a, 4b. On 2a and 2b the mean percentages were the same in the first 5 years after the liming in 1897. On Plots 4 and 5, however, the corresponding mean percentages were lower on

the limed portions, the relevant averages being, 1898–1902 : Plot 5a, 2·23, Plot 5b (2 tons lime), 1·98 ; 1912–16 : Plot 5a, 2·00, Plot 5b (2 tons lime), 1·78 ; 1915–19 : Plot 4a, 1·71, Plot 4b (1 ton lime), 1·65. The number of plots available is too few to tell whether this is a real effect.

The linear regression of nitrogen content on yield of grain was worked out for Plots 1, 3, 4, 5, 6, 9, and 11b, for the period 1882–1926. Deviations from 8-year means were taken in each case, to eliminate as far as possible the long-term changes in the yields. The regression coefficients were all negative, indicating that high yields are associated with low nitrogen content in the grain, and *vice versa*, and the regressions were significant on three of the seven plots, 6, 9, and 11b. The average of the seven regression coefficients was − ·020, so that an increase in yield of grain of 1 cwt. per acre was accompanied by a decrease in the nitrogen content of ·02.

Effects of Meteorological Factors on Nitrogen Content.

The regression functions of the nitrogen content on the rainfall in 6-day periods from mid-February until the end of August were worked out by Fisher's method for Plots 1, 3, 4, 5, 6, 7, and 11b for the period 1885–1926.

The effects of the change of manuring in 1907 were assumed to be too small to necessitate a division of the period, since on none of the six plots to which the curves were fitted was the difference in mean percentages before and after 1906 significant, though there were, as pointed out above, indications of an effect of the change in manuring. In fitting the regression functions, any trend throughout the period 1885–1926 was eliminated from the rainfall and nitrogen figures by fitting fifth degree polynomials. These regressions give curves showing the change in the percentage expected from an inch of rain above or below the average at any time in the 6 months considered. In marked contrast with the results for yields of grain, the regressions were all

significant, that for Plot 5 at the 5 per cent. point and all the others at the 1 per cent point. The rainfall curves for the different plots are all similar in shape, and give no indication that differences in manurial treatment influenced the rainfall effect. The average curve for the seven plots is shown (Fig. 21).

Rainfall above the average in the months May, June, and July reduced nitrogen content. The period of most marked

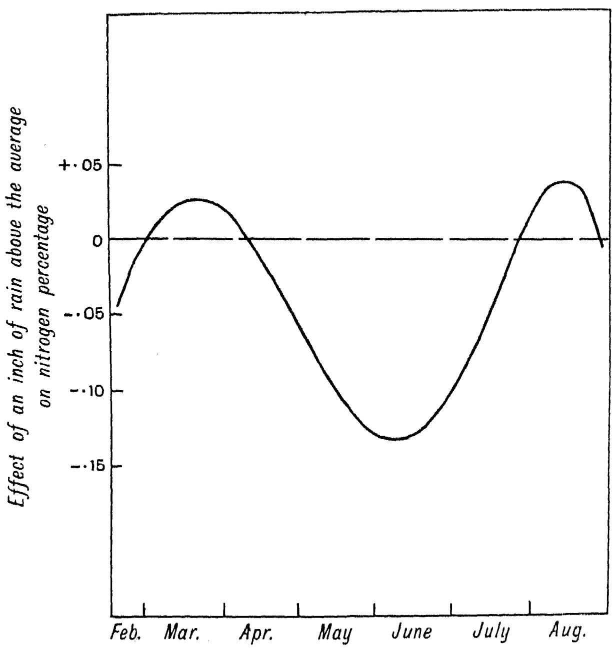


FIG. 21.—Barley: average curve for seven plots.

effect was at the beginning of June; at this time an inch of rain above the average caused a reduction of about 0·10. Rainfall in early spring had little effect, beyond a slight tendency to raise the nitrogen content.

The regression of nitrogen content on the maximum daily temperature in the period from mid-February to the end of August was significant on all plots except 11b. The differences between the curves for different plots were rather

more marked than for rainfall. Three curves are shown, Figs. 22, 23, 24, the mean of Plots 1, 4, and 7, the mean of Plots 3 and 6, and Plot 11b. On all plots high temperatures

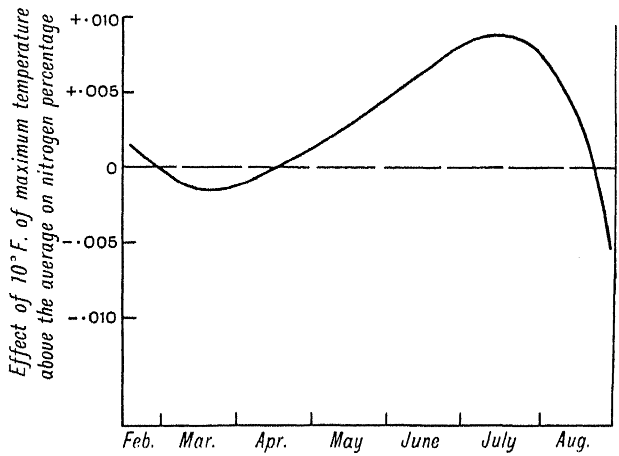


FIG. 22.—Barley.
Mean of plots 1, 4, 7: no nitrogen.

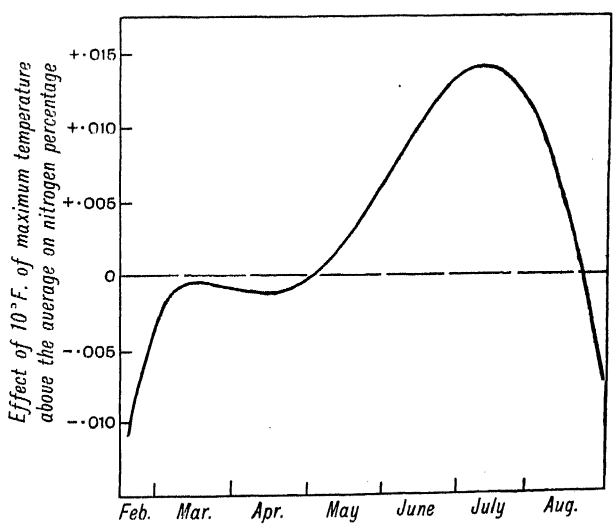


FIG. 23.—Barley.
Mean of plots 3, 6: nitrate of soda.

from the middle of May until harvest tended to increase percentages. An additional 5° C. (or 9° F.) to the total of the maximum daily temperatures in the second week of July raised the nitrogen content by about ·0076 on Plots 1, 4, and 7, ·0128 on Plots 3 and 6, ·0083 on Plot 5, and ·0059 on Plot 11b. On Plots 1, 4, 7, and 11b variations in temperature in early spring had little effect, but on Plots 3, 5, and 6 temperatures above the average in the second half of February tended to lower the nitrogen content.

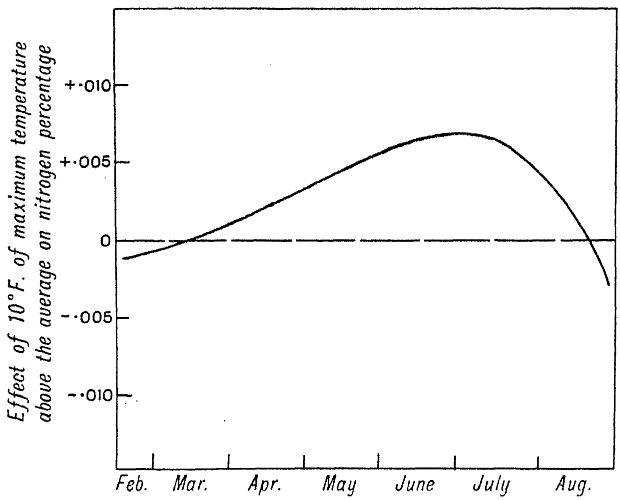


FIG. 24.—Barley.
Plot 11b: farmyard manure.

The linear regression of the average nitrogen content of Plots 1, 7, 4, 3, 6, and 11b in the period 1885–1926 was worked out on the sowing date, measured as the number of days from February 26, the earliest sowing date.

The regression equation was

$$\text{Nitrogen content} = 1{\cdot}61 + {\cdot}0067\ D,$$

D being the number of days later than February 26, and was significant at the 1 per cent level. Thus late sowing gave higher percentages than early sowing.

Summary of the Results for Barley.

The principal effects of the manuring were an increase in nitrogen contents given by nitrate of soda or sulphate of ammonia and a decrease given by minerals, each manure producing its effect both in presence and absence of the other. The acidity of the sulphate of ammonia plots had no marked effect on the nitrogen content.

There was no evidence of any progressive change in the percentages throughout the period, except that caused by the changes of manuring in 1907.

The percentages tended to be higher in seasons in which the yield was low than when it was high.

Both rainfall and maximum temperature throughout the period of growth produced significant effects, though it is not known whether these are really separate. Warm dry weather from May until harvest gave high percentages.

There was also a significant effect of sowing date, late sowing raising the nitrogen content.

The Nitrogen Content of Wheat Grain.

For five of the wheat plots, 1, 4, 3, 6, and 11b, the nitrogen content in the dried grain was determined for each year from 1883 to 1926, and provides material for a study of manurial and meteorological influences on nitrogen content of wheat. No figures are available for the years 1893 and 1894, and there are one or two further omissions in individual plots, but the series is reasonably complete (cf. Table 115).

The varieties of wheat were frequently changed, but as most of them were grown for a few years only, the effect of the changes on the nitrogen contents cannot be estimated.

Effect of Manuring on Nitrogen Content.

The average nitrogen contents on Plots 1, 3, 4, and 6 are shown in Table 62, the periods 1885–1906, 1907–26 being kept apart because of the changes in manuring in 1906–7.

TABLE 62.—MEAN NITROGEN CONTENT OF WHEAT, 1885–1926.

	1885–1906.		1907–1926.	
	No Minerals.	Minerals.	No Minerals.	Minerals.
No nitrate of soda .	(1) 2·02	(4) 2·09	(1) 1·87	(4) 1·89
Nitrate of soda . .	(3) 2·20	(6) 2·16	(3) 1·95	(6) 1·91

The addition of nitrate of soda increased the nitrogen content both in presence and absence of minerals. The effect of minerals, if any, was small. The corresponding figures for the farmyard manure plot were 2·11 in 1885–1906 and 1·97 in 1907–26.

The mean content was in all cases considerably smaller in the last 20 years of the experiments. Within each of the two periods 1885–1906, 1907–26, however, the percentages showed, like the barley figures, no tendency to fall on any of the plots. The change after 1906 is less easy to interpret than the corresponding changes for barley. It cannot be attributed to a decrease in the applied nitrogen, since it occurred also in the crops receiving no manure and mineral manures only, nor does it appear to be due to a change in variety, since Square-head's Master was grown, with only one exception, each year from 1904 to 1912. A gradual tendency to fall may have been masked by a few exceptional years about 1906.

Relation Between Nitrogen Content and Yield of Grain.

The linear regressions of nitrogen content on the yield of grain were worked out for all plots, taking deviations from 5-year means to eliminate the effect of the fall in yields. They showed, as with barley, that the nitrogen content tends to be low in seasons which give high yields, the regression coefficients being negative in all cases and significant on Plots 1, 3, and 6. With yields measured in cwt. per acre, the regression coefficients were: Plot 1 (no manure) — ·0325; Plot 4 (minerals) — ·0243; Plot 3 (nitrate of soda) — ·0149;

Plot 6 (minerals plus nitrate of soda) — ·0271 ; Plot 11b (farmyard manure) — ·0101. Thus an increase in yield by 1 cwt. per acre in a year may be expected to be accompanied by a fall in nitrogen content of about ·021, which agrees closely with the corresponding estimate for barley.

The Effect of Meteorological Factors on Nitrogen Content of Wheat Grain.

No effect of rainfall during the winter months September to February on nitrogen content could be found on inspection. The period from mid-February until the end of August was accordingly taken in calculating the curves showing the linear effects of an inch of rain above the average falling at any time. The linear regression function, from which the curves are derived, was significant on all five plots, and reached the 1 per cent level on Plots 4, 6, and 11b. The curves are similar in general shape on all plots ; the curves for Plots 6 and 11b are shown in Fig. 25. There are two periods, centred near the end of March and the middle of August respectively, during which extra rain increases nitrogen content, and these are separated by a period, centred near the end of May, in which heavy rain decreases the percentages. As a result of this alternation of effects, the regression coefficient which represents the effect of the average rainfall in the period mid-February to August,

TABLE 63.—EFFECTS OF AN INCH OF RAIN ABOVE THE AVERAGE ON NITROGEN CONTENT OF WHEAT GRAIN.

Plot.	Approximate Time of Year.		August 9–15.
	March 18–24.	May 26–June 22.	
1 (no manure)	+ ·016	— ·058	+ ·049
4 (minerals)	+ ·033	— ·054	+ ·060
3 (nitrate of soda)	+ ·022	— ·064	+ ·123
6 (minerals + nitrate of soda)	+ ·050	— ·092	+ ·124
11b (farmyard manure)	+ ·033	— ·072	+ ·077

ignoring the distribution of rain, was not significant on any of the plots.

The effects are smaller in size than for barley. The manuring has had no appreciable influence on the positions of the turning-points in the curve, i.e. on the three times at which

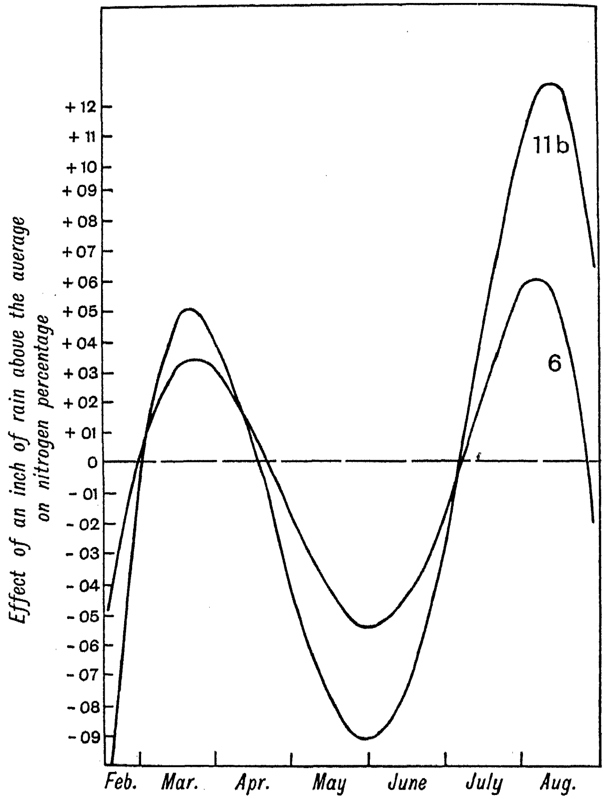


FIG. 25.—Wheat.
Plots 6: minerals plus nitrate of soda.
11b: farmyard manure.

the maximum rainfall effects occur, but the addition of nitrogen has increased the size of the effects of an inch of rain at these times. These are shown in Table 63.

The effect of rainfall just before harvest is of interest. Round about harvest time an inch of rain above the average

in the period August 9–15 is associated with an increase of about ·05 in nitrogen content on the plots without added nitrogen and ·12 on the plots receiving nitrate of soda. Harvesting generally took place in the latter half of August, but in one or two years it was near the beginning of the month. The effect of dry conditions in May and June in raising nitrogen content was also observed for barley.

No significant connection could be found between nitrogen content and the maximum temperature in the four months May, June, July, and August, each taken separately.

Summary of the Results for Wheat.

Nitrate of soda increased nitrogen content both in presence and absence of minerals, which had little effect.

Nitrogen content was higher in seasons of low yield than in seasons of high yield.

Variations in rainfall in spring and summer had a significant effect on nitrogen content. As with barley, dry conditions in May and June raised nitrogen content.

CHAPTER XIII.

THE CAKE AND CORN FEEDING EXPERIMENTS.

THE yields are shown in Tables 129–34.

The statistical examination of the results of the rotation experiments consists of three parts :—

(1) Tests of significance of the differences in yield on plots receiving different treatments. The treatments were arranged systematically within the blocks and occupied the same relative positions in all four blocks. Apart from this, however, the design does not differ from that of modern rotation experiments at Rothamsted, in which the cumulative effects of treatments are being studied.

(2) The mean yields and rates of deterioration on the rotation plots are compared with those on the permanent plots in the same field to find what part a rotation of crops plays in maintaining soil fertility.

(3) The influence of the fertility gradient on the validity of the comparisons is studied. Unfortunately the information about the relative fertilities of different parts of the field is not very reliable.

Tests of Significance of the Treatment Differences.

First Period, 1877-84.

The manures and mean yields per acre in this period are given in Table 64. In the following discussion the mean yields are calculated from the year in which the complete rotation started with roots ; 1877 for block II, 1878 for IV, 1879 for I, and 1880 for III. A change in manuring was

made, however, before blocks I and III had completed two cycles measured from the first root crop. The wheat crop has therefore been taken from 1878 to 1884 instead of from 1880 to 1886.

TABLE 64.—TREATMENT AND YIELDS. ROTATION EXPERIMENTS. SERIES 1, 1877–85.

Manures Applied, 1877-85.

Crop.	Plot 1.	Plot 2.	Plot 3.	Plot 4.
	Farmyard Manure.			
Roots	1000 lb. cotton cake	1000 lb. maize-meal	Nitrate of soda (248 lb.) and minerals (=plot 1)	Nitrate of soda (80 lb.) and minerals (= plot 2)
Barley	Roots fed-off	Roots fed-off	Roots fed-off, 124 lb. nitrate of soda	Roots fed-off
Seeds.	None.			
Wheat	Seeds fed-off, 672 lb. cotton cake	Seeds fed-off, 728 lb. maize-meal	Seeds fed-off nitrate of soda (275 lb.) and minerals (= plot 1)	Seeds fed-off nitrate of soda (58 lb.) and minerals (= plot 2)

Mean Annual Yields per Acre :—

	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Standard Error.
1877–84 Roots, tons . .	14·39	13·75	17·78	14·94	0·21=1·4%
1878–85 Barley, Grain, cwt. .	23·0	22·6	24·2	21·6	0·49=2·1%
Straw, cwt. .	30·6	30·5	35·1	30·6	0·23=0·7%
1878–85 Wheat, Grain, cwt. .	22·6	23·6	22·8	23·0	—
Straw, cwt. .	48·4	48·8	53·6	50·8	—

Since each treatment is applied to a plot in each of the four blocks, there is fourfold replication. But as each treatment is confined to the same plot throughout, the comparison of two treatment means is affected by differences

in fertility between different plots in the same block. Each plot measured one acre, and these differences may be considerable.

The estimate of error obtained by an analysis of variance is vitiated by the absence of randomisation, but in view of the particular arrangement of the plots, it is unlikely to be too high and may be regarded as a lower limit to the variation. Where the treatment differences clearly show no sign of significance, the standard error has not been calculated.

Roots.—It was assumed that the standard errors of the two root crops, swedes and mangolds, would not differ substantially; and the yield data were combined. The analysis was carried out as that of four randomised blocks of four plots each, each plot yield being the mean of its yield in the two separate rotations. The estimated standard error obtained for the mean yield figures given in Table 64 was 0·21 ton per acre, or 1·4 per cent, based on 9 degrees of freedom. On this error the differences between Plot 3 and Plot 1, Plot 4 and Plot 2, and Plot 3 and Plot 4 are significant, but that between Plot 1 and Plot 2 is not significant. Thus the artificials gave significantly higher yields than the corresponding farmyard manure plots, and the artificial Plot 3 corresponding to cotton cake gave higher yields than Plot 4 corresponding to maize-meal, the difference being 2·84 tons per acre. The difference in mean yields of the cotton cake and maize-meal plots, 0·64 ton per acre, is not significant.

Barley.—The standard errors calculated as above were: grain, 0·49 cwt. per acre, or 2·1 per cent: straw, 0·23 cwt. per acre, or 0·7 per cent. The increase in yield given by the nitrate of soda on Plot 3 is significant both in the grain and the straw, the increase in grain, 2·6 cwt. per acre, corresponding to an increase of about 16 lb. grain per lb. of nitrogen added. The residual effect of farmyard manure was greater than that of nitrate of soda on the yield of grain, but not significantly so. There was no appreciable difference in residual effect between cotton cake and maize-meal.

Wheat.—The yields of grain were similar on all four plots. The nitrate of soda given to Plots 3 and 4 increased the straw by 5 and 2 cwt. per acre respectively. The yields were high.

Second Period, 1885-98.

Details of the changes in the design of the experiments in 1885 will be found on p. 12. The manures and mean yields per acre in this period are set out in Table 65.

Swedes.—The swedes followed 3 years after the crop that had received the manures. The mean yields on all four plots lie close together; no residual effect can be detected. The crop suffered from attacks of finger-and-toe disease, with the result that there was no crop in 1890 and only about 1½ tons per acre in 1892.

Mangolds.—The estimated standard error of a mean yield is 0·35 ton per acre, based on 9 degrees of freedom so that there was no difference between the residual effects, if any, of the treatments given during the two previous rotations. The yields fell slightly during the 12 years.

Barley.—The increment of 3·2 cwt. of grain per acre given by the additional 18 lb. of nitrogen supplied to Plot 3 is significant, but the difference 1·6 cwt. per acre in yield of grain between the plot receiving cotton cake and that receiving maize-meal is not significant. The results for straw are similar; nitrate of soda gave a significant increase, but cotton cake as compared with maize-meal did not. Unlike the results for the root crop in the first period, however, the yields on the nitrate of soda plots are not significantly higher than those on the cake and meal plots either in grain or in straw.

Clover.—The manures applied to the preceding barley crop appear to have had a residual effect on the clover, the mean yield of Plots 1 to 4 being 20 per cent higher than those of Plots 5 to 8. This is mainly due to a difference in the rate of deterioration of yields on the manured and unmanured plots. There was, however, no difference in the residual effect of the different applied manures.

TABLE 65.—ROTATION EXPERIMENT. MANURES AND YIELDS PER ACRE. SECOND PERIOD, 1885–98.

	Plot 1.	Plot 2.	Plot 3.	Plot 4.
Swedes . .	3 cwt. super.			
Barley . .	$3\frac{1}{2}$–$5\frac{1}{2}$ tons roots fed-off with			
	400 lb. cotton cake	400 lb. maize-meal	no cake or meal artificials (= Plot 1)	artificials (= Plot 2)
Clover . .	No manure			
Wheat . .	No manure			

Plots 5–8. No Manure.

Mean Yields per Acre: Plots 1–4, Swedes and Barley Manured.

	Plo 1.	Plot 2.	Plot 3.	Plot 4.	Standard Error.
1885–96					
Swedes, tons .	9·13	9·51	9·44	9·05	—
1886–97					
Barley, Grain, cwt.	18·3	16·7	19·9	16·7	± 0·54
Straw, cwt.	22·2	19·9	24·6	21·0	± 1·10
Clover[1] cwt. . .	42·9	44·7	48·3	46·0	—
1888–99					
Wheat, Grain, cwt.	19·2	18·8	19·1	19·1	—
Straw, cwt.	29·1	28·1	28·1	28·1	—

Plots 5–8. All Crops Unmanured.

	Plot 5.	Plot 6.	Plot 7.	Plot 8.	Standard Error.
1885–96					
Mangolds, tons .	11·17	11·46	11·77	10·78	±0·35
1886–97					
Barley, Grain, cwt.	12·5	12·5	13·2	12·5	±0·62
Straw, cwt.	14·3	14·9	15·9	15·2	±0·47
Clover, cwt. . .	36·0	39·2	39·3	37·3	—
1888–99					
Wheat, Grain, cwt.	17·8	17·6	17·8	17·5	—
Straw, cwt.	26·0	25·4	25·9	25·3	—

[1] The yields of clover-hay should have been taken from 1887 to 1898, but tares and peas were grown in 1887 and peas in 1896, and these years are omitted from the averages.

Wheat.—The mean yields of Plots 1 to 4 are very similar, as also are those of Plots 5 to 8; the former (the manured plots) being about 9 per cent higher than the latter (the unmanured).

Fourth Period, 1905-10.

The data for this period are scanty: for each rotation they must be measured from the year in which the manured crop was grown. Farmyard manure raised the mean yield of roots on Plots 5 to 8 about 35 per cent above that of Plots 1 to 4, but neither cotton cake nor maize-meal caused any further increase. Of the other three crops Plot 6 gave the highest yield in each case.

On Plots 1 to 4 there were no significant differences in the yields of swedes or of wheat, and maize-meal had no effect on barley and mustard also. Both barley and mustard benefited from the cotton cake. The increment of 5·7 cwt. per acre barley straw given by Plot 1 over Plot 2 is significant at the 1 per cent point, but the increments of grain and mustard are not significant.

There is nothing to add to the description already given of the fifth and sixth periods (cf. pp. 18–22).

Summary.

It is clear that cotton cake has shown no definite advantage over maize-meal. The comparison of direct applications was made on three crops: roots, in the first and fourth periods; barley, in the second and fourth periods; and wheat, in the first period. The results were:—

Roots.—In the first period (1878–85) the cotton cake plot gave a mean increment in yield over the maize-meal plot of 0·64 ton per acre, the difference in nitrogen supply being about 33 lb. per acre per annum. The increment was not significant. As against this 45 lb. nitrogen given to Plot 3 as nitrate of soda caused a significant increment of 2·84 tons

TABLE 66.—ROTATION EXPERIMENT. MANURES AND YIELDS PER ACRE. FOURTH PERIOD, 1904–11.

Manures Applied.

Crop.	Plot 1.	Plot 2.	Plots 3 and 4.	Plot 5.	Plot 6.	Plots 7 and 8.
Swedes	No manure			Farm-yard manure (4 tons per acre) from cotton cake	maize-meal	no cake or meal
Barley	12 tons roots fed with 920 lb. cotton cake	920 lb. maize-meal	No cake or meal	12 tons roots fed on each plot		
Mustard	No manure			No manure		
Wheat	No manure			No manure		

Yields per Acre.

	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Standard Error.
1908–10 Swedes, tons	9·57	10·21	11·11	9·95	—
1905–10 Barley, Grain, cwt.	23·3	20·5	20·3	20·4	1·16
Straw, cwt.	31·7	26·0	25·7	25·5	1·04
1906–10 Mustard, cwt.	85·3	75·7	80·4	72·5	7·4
1907–10 Wheat, Grain, cwt.	11·0	11·4	11·3	11·6	—
Straw, cwt.	17·3	17·3	16·7	17·2	—

	Plot 5.	Plot 6.	Plot 7.	Plot 8.	
1907–10 Swedes, tons	13·92	14·11	14·64	14·08	—
1908–10 Barley, Grain, cwt.	18·6	20·0	18·3	17·7	—
Straw, cwt.	22·5	25·3	22·4	22·0	—
1909–10 Mustard, cwt.	87·5	93·8	83·0	70·2	—
1910–11 Wheat, Grain, cwt.	6·9	8·4	7·4	6·4	—
Straw, cwt.	10·6	12·3	10·9	9·9	—

per acre over Plot 4, and the yields on the nitrate of soda plots were significantly higher than those on the cake and meal plots. The roots crops were mangolds for 5 years and swedes for 3 years. The land was in good condition, and omitting 2 years in which the mangolds suffered badly from finger-and-toe disease the yields were about 19 tons per acre for mangolds and 18 for swedes.

In the fourth period the crop was swedes, and cotton cake (on Plot 5) supplied about 30 lb. more nitrogen per acre than maize-meal (on Plot 6). There were no visible effects of either manure, the yields on Plot 6 being above those on Plot 5, but both below the mean yield of the plots which received neither cake nor meal. In this series no equivalent artificial dressings were given. The mean yields were about 14 tons per acre.

Barley.—The barley crop received the manures on Plots 1 to 4 in the second and third periods. In the second period an attempt was being made to reduce the level of fertility of the land, and the cotton cake supplied only 18 lb. more nitrogen per acre than the maize-meal. The mean responses to this in the period 1886–97 was 1·6 cwt. of grain, 2·3 cwt. of straw per acre, neither being significant. The increment given by the 18 lb. nitrogen of the equivalent nitrate of soda dressings was 3·2 cwt. grain, 3·6 cwt. of straw per acre, both being significant. In this case, however, the yields on the nitrate of soda plots were not significantly above these in the cake and meal plots. The mean yields were about 17 cwt. of grain and 21 cwt. of straw per acre.

The corresponding increments of the cotton cake plot in the third period were 2·8 cwt. grain, 5·7 cwt. straw per acre, with about 42 lb. difference in nitrogen content per acre. The figure for straw was significant, but not that for grain. The maize-meal plot showed no advantage over the plots without cake or corn, but yields as a whole had increased since the last period to 20 cwt. of grain and 26 cwt. of straw per acre.

Wheat.—In this case the yields were high on all four plots and the crop clearly had no need of nitrogen, there being no response even to the artificial dressings.

The comparisons of direct applications appear to have been made on all occasions on land which was yielding fairly good crops. Whether cotton cake would show to better advantage compared with maize-meal on poorer land cannot be learned from the above results. With conditions as they were, however, the conclusions of the experiment are that the cotton cake has not significantly increased yields, while the slightly higher "equivalent" dressings of nitrate of soda did give significant increases under the same circumstances.

There is very little evidence of any difference in residual effects of the various manures. The crops following one year after a direct application of manures were: barley in the first period, clover in the second, and mustard (Plots 1 to 4) and barley (Plots 5 to 8) in the third. The cotton cake plot gave higher yields than the maize-meal plot on two of these; barley (first period) and mustard (third period), but lower in the other two.

Deterioration of Yield as Compared with the Continuous Wheat and Barley. Barley, First Period, 1877-85.

As on the permanent plots in the same period, the barley yields showed an upward trend on all four plots. Plots 1, 2, and 4 gave yields slightly above that of permanent Plot 6; Plot 3 was about 3 cwt. per acre below permanent Plot 9.

Second Period, 1886-98.

The yields of barley fell steadily during this period as is shown by breaking it up into three periods of 4 years each (Table 67).

TABLE 67.—AVERAGE YIELD OF BARLEY GRAIN, CWT. PER ACRE PER ANNUM. FOUR-YEAR PERIODS, 1886–97.

Grain, cwt. per Acre.				
	Plot 1.	Plot 2.	Plot 3.	Plot 4.
1886–89 . .	20·3	18·7	22·3	19·5
1890–93 . .	18·9	17·3	20·8	16·2
1894–97 . .	15·6	14·2	16·5	14·4
	Plot 5.	Plot 6.	Plot 7.	Plot 8.
1886–89 . .	14·6	15·0	16·8	15·8
1890–93 . .	13·7	12·5	13·4	12·8
1894–97 . .	9·3	10·1	9·4	8·9

The average fall in yield of grain in a year throughout the period 1885–98 on each plot is :—

Mean Annual Decrements. Cwt. per Acre.				
	Plot 1.	Plot 2.	Plot 3.	Plot 4.
Actual	·89	·80	·89	·80
percentage .	4·9	4·8	4·5	4·8
	Plot 5.	Plot 6.	Plot 7.	Plot 8.
Actual	·79	·77	1·01	·96
percentage .	6·3	6·2	7·7	7·7

The actual annual decrements are on the whole no greater on the unmanured plots than on the manured. The yields on Plots 5 and 6, which had formerly received farmyard manure, fell less rapidly than those on Plots 7 and 8. This may point to a residual effect of the farmyard manure, but in view of the small numbers of years available it is not certain that the effect is real.

Comparison of the First 20 Years with the Continuous Barley.

The mean yield and average fall in yield of grain per annum in the period 1878–97 for each of Plots 1 to 4 are in cwt. per acre :—

	Plot 1.	Plot 2.	Plot 3.	Plot 4.
Mean yield	20·2	19·1	21·6	18·7
Mean annual decrement . .	0·44	0·50	0·44	0·41
Nitrogen in manure (lb. per acre), 1878–85, 1886–97 .	— 23	— 5	19 23	— 5

In addition, the plots also received nitrogen from the folding of the root crops, the amount fed off averaging 15 tons per acre in 1878–85 and about 4·5 tons per acre in 1886-97.

The corresponding data for the continuous plots which received nitrate of soda or farmyard manure are in cwt. per acre:—

	Plot 3a, Nitrate of Soda.	Plot 6, Nitrate of Soda + Minerals.	Plot 9a, Nitrate of Soda + Minerals.	Plot 11b, Farmyard Manure.
Mean yield	16·2	20·5	22·4	18·8
Mean annual decrement . .	0·45	0·29	0·36	0·05
Nitrogen in manure (lb. per acre)	41 —	41 —	82 —	110 —

The rates of deterioration on the permanent plots with complete artificial manures are slightly less than on the rotation plots, the latter having fallen more steeply in the period 1886–97. The rotation Plots 1 and 2 had mean yields above that of the continuous Plot 11b, which received farmyard manure supplying 110 lb. nitrogen per annum. On Plot 11b, however, the yields showed practically no tendency to deteriorate, so that they were higher than on Plots 1 and 2 in the last few years of the period.

In comparing the organic and artificial manures, there are two points of difference between the rotation and continuous plots. On the rotation plots the yields of Plots 1 and 2, which received sheep droppings, deteriorated in exactly the same manner as those of Plots 3 and 4, which had nitrate

of soda, whereas in the continuous barley the farmyard manure plot showed markedly less deterioration : the dressing of farmyard manure, however, was heavy and it was repeated annually.

Further, the average difference in yield of grain between the rotation Plots 3 (nitrate of soda) and 1 (cake-fed sheep droppings) was 1·5 cwt. per acre in favour of the former, which is practically the same as the difference for the permanent Plots 6 (nitrate of soda) and 11b (farmyard manure), (1·7 cwt. per acre). But Plot 1 (rotation) received less nitrogen in its manure than Plot 3, whereas Plot 11b had nearly three times as much as Plot 6.

In the 4 years 1899–1902 in which the barley was grown without manure the yields fell, the mean yield being 10·2 cwt. of grain, as against 18·5 cwt. on permanent Plot 6 in these years.

The Fourth Period, 1905-10.

When the rotations were resumed in 1905, the yields rose at once. The mean yields of grain in 1905–10 were Plot 1 (46 lb. nitrogen per acre), 23·3 cwt. ; Plot 2 (10 lb. nitrogen), 20·5 cwt. ; Plots 3 and 4 (no nitrogen), 20·4 cwt.

These were considerably above those of the period 1886–97, and they were higher than on any of the permanent plots, the highest mean yields of grain on the latter during 1905–10 being 18·2 cwt. per acre on Plot 11b (farmyard manure), and 18·3 cwt. per acre on Plot 9 (minerals and nitrate of soda). The yields on the rotation plots were slightly less during the period 1908–10 than in 1905–7, but the period is too short to detect deterioration unless very marked.

The Fifth and Sixth Periods.

The mean yield of grain in the period 1910–31 dropped to little more than half that in 1905–10. The general level of yield was falling slightly within the period.

Deterioration of Yield: Wheat.

The yields rose slightly during the first two rotations, the mean yields per acre per annum over all plots being 21·0 cwt. (grain) and 47·1 cwt. (straw) in the first rotation, 1878–81, and 25·0 cwt. (grain) and 53·7 cwt. (straw) in the second. The level of grain yields dropped on the change in manuring in 1886, following which the manures were no longer applied to wheat, but showed no tendency to fall, however, throughout the next three rotations and in the period 1878–99 as a whole deterioration was negligible. The fall in straw yields in 1886 was much greater than for grain, and the mean yield of straw on Plots 1–4 in the second period, 1888–99, was 28·3 cwt. per acre as against 50·4 cwt. per acre in the first period, 1878–85. The straw yields dropped slightly in the course of the three rotations of the second period.

The mean yields of Plots 1 to 4 in the period 1878–99 are shown in Table 68, the comparable plots in the continuous wheat being included.

The yields on the rotation plots are well above those on any of the comparable continuous plots.

In the period 1905–10, mustard preceded wheat instead of clover. The yields were about the same in the years 1905 and 1906 as in the second period, but dropped rapidly during the next 4 years.

Unlike barley, the wheat yields increased slightly in 1911–33 from those of the period 1907–10. This may be partly due to the reinstatement in 1918 of clover as the crop preceding wheat; the mean yields of grain were 11·4 cwt. per acre in 1911–17 and 13·9 cwt. in 1918–31 as against 11·3 cwt. in 1907–10. The yields do not appear to be deteriorating; in 1933, which was a season favourable to wheat, the plot yielded 15·3 cwt. of grain.

The value of the rotation and the folding of roots in maintaining yield without heavy dressings of organic manure

TABLE 68.—MEAN YIELDS, 1878–99.

Grain, cwt. per Acre.				
	Plot 1.	Plot 2.	Plot 3.	Plot 4.
Mean Yield	20·1	20·0	20·0	19·9
Nitrogen in manure, lb. per acre:				
1878–85	39	9	43	9
1886–99	None	None	None	None
	Plot 3a (Nitrate of Soda).	Plot 6.	Plot 9a.	Plot 11b.
Mean yield	11·4	16·0	17·2	14·4
Nitrogen in manure, lb. per acre	41	41	82	110
Straw, cwt. per Acre.				
	Plot 1.	Plot 2.	Plot 3.	Plot 4.
Mean yield	35·4	34·7	36·5	35·4
	Plot 3a.	Plot 6.	Plot 9a.	Plot 11b.
Mean yield	23·2	30·4	37·2	26·9

is shown in Table 77, page 253, in which the mean yields of the cotton cake plot and the permanent manure plot are compared.

After 1885 the organic manure given to the barley was the only nitrogenous dressing which the land received during the whole rotation; thus the rotation barley crop was being grown on land receiving nitrogen only once in 4 years, whereas the permanent barley was on land receiving nitrogen every year.

The Relative Fertility of the Different Blocks.

The systematic arrangements of the treatments within each block has the unfortunate consequence that any fertility gradient over the field would appear as part of the treatment differences.

Examination of the data reveals no evidence that variations in soil fertility within the blocks seriously affected the

treatment comparisons. The results of the tests of significance are quite consistent; there are no anomalies, and the only definitely significant results are those from direct application of the manures. A possible gradient suggested by the results is one rising from blocks IV. to block I.; if this existed the superiority of cotton cake over maize-meal would be under-estimated, and that of nitrate of soda over the organic manures would be over-estimated.

The relative fertilities of the different blocks over one or more complete rotations can, however, be estimated by combining all four crop yields in order to equalise as far as possible the effects of the season. There are several methods of reducing the yields of different crops to a comparable basis. One is to express the yield of each crop in any year as a percentage of its total yield in the period under consideration. This has the disadvantage that the comparison is decided mainly by the more variable crops. An alternative method which avoids this disadvantage is to divide each crop yield by an estimate of its standard error. The equalisation of the effects of the season thus effected is necessarily crude, and in any case it attributes to block fertility effects of disease and insect attacks, and it takes no account of different rates of deterioration of the different crops.

No estimate is possible for the first period, as the "seeds" crops were not weighed. For the period 1888–98 estimates were made by both methods, but three rotations could not be used as the seeds crop was not always clover; and, as the swedes failed in 1890 and 1892 owing to disease, the root figures were taken from Plots 5 to 8 only. Estimates were made for the complete rotation on Plots 1 to 4 in the period 1907–10. The mean values obtained from the four blocks in the two periods by the methods of dividing each crop by its standard error are:—

Block	I.	II.	III.	IV.
1888–95	3·68	3·96	3·62	3·41
1907–10	2·34	1·99	3·00	2·60

A third and more reliable estimate can be obtained in the period 1900–2, when barley was grown on each block without manure. The mean yields of grain in cwt. per acre in these years were :—

Block	I.	II.	III.	IV
1900 . . .	12·5	13·1	19·3	8·7
1901 . . .	13·6	18·3	19·9	19·4
1902 . . .	18·5	23·2	25·1	18·7
Mean 1900–2	14·9	18·2	21·4	15·6

The fertility of blocks III. and IV. relative to that of I. and II. seems to have been increasing throughout the period 1886–1910. The figures, for what they are worth, give no evidence of a fertility gradient rising from block IV. to block I., except possibly at the beginning of the experiments.

PART III.—THE RESULTS: THEIR BEARING ON AGRICULTURAL SCIENCE AND PRACTICE.

BY SIR E. J. RUSSELL, D.SC., F.R.S.

CHAPTER XIV.

EFFECTS OF ARTIFICIAL MANURES AND OF FARMYARD MANURE

Similarity of Yield of Total Produce of Wheat and Barley.

THE yield of total produce of wheat was in general not far from that of barley except on the plots receiving sulphate of ammonia where acidity came into play. The mean excess of total produce of wheat over that of barley for the whole period of 50 years was :—

Plot.	1.	7.	4.	3.	6.	9 With Nitrogen.	9 No Nitrogen.	10a.[1]	10b Rape Cake.	11a.[1]
Lb. per acre .	37	302	−45	335	96	−144	−583	143	502	−425
Per cent of mean yield . .	2·0	16·4	−2·3	10·4	2·4	−3·0	−24·8	5·7	15·4	15·0

Where sulphate of ammonia was given the differences were greater :—

[1] 1882–1926 only.

Plot.	2.	5.	8 With Nitrogen.	8[1] No Nitrogen.
Lb. per acre . .	206	1306	842	472
Per cent. of mean yield	11·2	44·3	26·5	25·3

In individual years there are considerable differences between wheat and barley, but no relation has been found between these differences and either the total yields or the climatic factors. Nevertheless, the problem remains one that merits further study.

Over averages of 5 years the results for wheat and barley total produce are so nearly the same that they can be taken together.

The Responses of Wheat and Barley to Nitrogenous Fertilizers.

The chief effect sought in the original plan of the experiments was that of nitrogen: potassic and phosphatic fertilizers were always applied together. The nitrogen was applied in three different forms and in four different quantities: as nitrate of soda, as sulphate of ammonia, and as farmyard manure. The first two supplied nitrogen at the rate of 41 and 82 lb. per acre, and the farmyard manure at rates not determined but probably about 53 and 105 lb. per acre.

There is no clear sign of any steady change of yield on the manured plots during the first 15 years of the experiment. The yields were high during the second period of 5 years but they were about the same during the third period as they had been during the first. We may therefore take the first 15 years together so as to eliminate the variations due to individual seasons.

[1] 1882–96 only.

During these years the effects of potash and phosphate without nitrogen had been only small. The effects of nitrogenous fertilizers taken alone had been greater, but the most marked results were produced by the complete fertilizer. This is now common knowledge, and the results, being given on pages 142–56, need not be repeated here.

The mixture of potash and phosphate thus benefits both wheat and barley, but the design of the experiment gives no information as to whether the potash or the phosphate is the more effective. An attempt was made after 30 years to discover this by altering the treatment of two plots so that one received nitrogen and phosphate only while the other received nitrogen and potash only. Two comparisons were intended, one with the plot receiving nitrogen only, the other with the plot receiving complete fertilizer. Unfortunately the comparisons are not really valid because of the widely different history of the plots, and no satisfactory conclusions can be drawn. Subsequent experiments on other parts of the field and elsewhere on the farm show that only in exceptional seasons do either potassic or phosphatic fertilizers have much effect on cereal crops grown in ordinary rotation at Woburn.

It will be shown later that these mineral fertilizers had two effects on the crop: they increased the total nitrogen uptake by the plant, presumably by fostering a greater root development, and they enabled the plant to produce more carbohydrate per unit of nitrogen taken up, thus increasing the efficiency of the nitrogen in the plant.

The effect of nitrogen is, however, very marked, especially when potash and phosphate are also added. The yields without nitrogenous fertilizer and the increase obtained with successive additions of nitrogen are given in Table 69.

The yields of total produce of wheat and barley differ only by about 10 per cent, while the increments given by nitrogen are even closer. It can hardly be an accident that the figures are so nearly alike, and it appears that the added

TABLE 69.—EFFECT OF NITROGENOUS FERTILIZERS IN PRESENCE OF POTASSIC AND PHOSPHATIC FERTILIZERS. MEAN YIELDS FOR 15 YEARS, 1877–91, CWT. PER ACRE.

	Yield without Nitrogen.	Additional Yield on Plots Receiving Nitrogenous Fertilizer.				
		41 lb. Nitrogen per Acre.		82 lb. Nitrogen per Acre.		105 lb. Nitrogen in Farmyard Manure.
		As Nitrate of Soda.	As Sulphate of Ammonia.	As Nitrate of Soda.	As Sulphate of Ammonia.	
	Plot 4.	Plot 6.	Plot 5.	Plot 9.	Plot 8.	Plot 11.
Total Produce :						
Barley .	23·4	26·7	21·1	37·3	32·3	16·7
Wheat .	26·2	25·5	22·3	36·1	35·1	16·7
Increment in lb. per lb. Nitrogen given in manure :—						
Barley .	—	73	61	51	44	18
Wheat .	—	70	58	49	48	18
Grain :						
Barley .	10·7	10·7	9·4	13·3	13·5	7·7
Wheat .	8·6	8·7	7·6	10·3	11·7	6·2
Ratio of Grain Total Produce:						
Barley .	46	43	45	40	42	46
Wheat .	33	33	34	30	33	34

nitrogen has led to substantially the same amount of additional growth for both crops.

The three manures have differed in effectiveness among themselves. The sulphate of ammonia in single, but not in double dressing, has been somewhat inferior to the nitrate of soda, and the farmyard manure has been considerably inferior, yet each one has acted in the same way on the wheat and on the barley.

Of the two artificial fertilizers the first dose of sulphate of ammonia added 21·4 cwt. and of nitrate of soda nearly 26·8 cwt. of total produce, while the second added only 13·4 cwt. to the sulphate of ammonia and 8·9 cwt. per acre to the nitrate of soda plots.

These figures are fairly close to those obtained at Rothamsted over the same period, and this suggests that the nitrogenous fertilizers in these long-continued experiments

act more or less independently of the soil, which indeed seems to have become more like an inert culture medium than an actual supplier of plant nutrients. The figures are given in Table 70.

TABLE 70.—INCREMENTS, LB. PER ACRE OF TOTAL PRODUCE AND OF GRAIN PER LB. OF NITROGEN SUPPLIED IN FERTILIZER, 1877–91.[1]

	Barley.			Wheat.		
	Rothamsted.	Woburn.		Rothamsted.	Woburn.	
	Single Dose.	Single Dose.	Double Dose.	Single Dose.	Single Dose.	Double Dose.
Nitrate of soda alone :						
Total produce	43	46	—	—	34	—
Grain	20	19	—	—	10	—
Nitrate of soda and minerals :						
Total produce	73	75	52	63	71	50
Grain	32	30	19	19	24	14

In the large number of barley experiments made on ordinary barley-growing farms under the Institute of Brewing scheme, the increment of grain per lb. of nitrogen supplied in the fertilizer was about 10 to 15, being thus only about one-half the above figures, in spite of the fact that the fertilizer dressing was only 1 cwt. sulphate of ammonia per acre, about one-half the single dressing given here. The German figures obtained by Lemmermann and by Nolte[2] are 17 to 18.

It will be shown later that the figures from the continuous plots at Woburn and at Rothamsted correspond to a recovery of about 80 per cent of the added nitrogen. In rotation practice a more usual figure for cereals is only about 40 or 50 per cent. It appears that, during the period when the continuous corn crops are at their best, they make better

[1] 41 lb. nitrogen at Woburn. 43 lb. nitrogen at Rothamsted.

[2] For details see " Artificial Fertilizers," Sir E. John Russell, *Ministry of Agriculture Bulletin*, No. 29, 1933, p. 20.

use of nitrogenous fertilizers than those grown in the ordinary rotation. This may be associated with the circumstance that in ordinary practice the corn crop obtains much of its nitrogen from residues of the previous year's manuring or cropping, while in continuous corn cropping it would obtain very little and so is more dependent on the nitrogen added in each year.

Ratio of Grain to Total Produce.

While both the wheat and the barley have made approximately the same total growth, they have made very different use of the plant substance they have built up. The barley has put about 45 per cent of its substance into grain, while the wheat has put only about 33 per cent : these figures show little tendency to change. At Rothamsted the figures are in the same order, but about 50 per cent of the total produce of barley and 35 per cent of the total produce of wheat is grain.

Manuring has had but little effect on the relative proportions of grain and straw. As shown in Table 69 the ratio both for wheat and for barley is lowest on the nitrate of soda plots ; this fertilizer tends to increase the straw slightly more than it does the grain, while sulphate of ammonia and farmyard manure have increased both about equally. As shown on page 139, there was in the good years a tendency for the straw to increase rather more than the grain where complete manures were given, but not where nitrogen was omitted ; here the grain increased more.

All the differences are small, however,[1] and it is remarkable that the barley during the first 30 years and the wheat during practically the whole period should have transmitted approximately the same proportion of their substance to form seed, whether they were grown on poor unmanured soil steadily falling in fertility, on soil becoming sterile

[1] *See opposite page for footnote.*

through increasing acidity, or on land enriched with farmyard manure or with complete artificial fertilizers. Such change as took place was in the direction of producing slightly more grain in proportion to the straw during the middle period of the experiment, a fact we cannot explain. This steadiness of the ratio is another instance of the remarkable stability of the plant under varying conditions of soil productiveness; it makes greater or less growth according to the supply of plant food, but the internal changes are much smaller. For wheat these ratios of grain to total produce are very similar to those obtained on Broadbalk Field at Rothamsted. The unmanured crop at Rothamsted has a higher ratio than at Woburn, but the difference is chiefly in the years 1882–1901, when the Rothamsted ratio was particularly high. For crops receiving farmyard manure and complete artificial fertilizers the values are approximately the same at both places, and at both they are lower than for the unmanured crop.

Effect of Sulphate of Ammonia on Soil Acidity.

For the first 30 years of the experiments the sulphate of ammonia was applied at the rate of 400 lb. per acre on Plot 8,

[1] Especially if one takes account of the changes of variety. Thus for barley the results have been :—

Period.	Variety.	Mean Value of Ratio.* Grain/Total Produce.	Mean Yield, lb. per Acre. Grain.	Mean Yield, lb. per Acre. Total Produce.
1881–1882	Chevalier	43·5	2238	5147
1883–1886	Golden Melon	44·9	2098	4678
1887–1891*	,, ,,	45·3	1737	3832
1892–1896	,, ,,	44·5	1481	3335
1897–1898*	,, ,,	42·0	1207	2872
1904–1908	Chevalier	45·3	1199	2646
1909–1912	Goldthorpe	36·8	779	2115
1913–1919	Chevalier	42·0	917	2202
1922–1926	Plumage Archer	35·5	557	1568

* Omitting 1888, 1899 and 1900 when other varieties were grown, and all data for Plot 2 after 1891.

when given, and 200 lb. per acre annually[1] on Plots 5 and 2. During the first 15 years the sulphate of ammonia behaved very much like the nitrate of soda. The effectiveness of its nitrogen as measured by the increments given over the corresponding plots without nitrogen, when that of the nitrate of soda is put at 100, was :—

	Barley.	Wheat.
Single dose (41 lb. N. per acre) alone (Plot 2). .	102	116
,, ,, ,, ,, + minerals (Plot 5)	87	88
Double dose (82 lb. N. per acre) + minerals (Plot 8)	96	115

To some extent, however, this result is artificial, for already in the 13th season, when the yield on the barley Plot 8 had begun to suffer, there is in the record book a note, dated July 26, 1889, stating that the produce of only one-half of Plot 8a was to be weighed, as the plant on the lower half of the plot was very inferior. In 1890, on June 4, it is recorded that "Plot 8a seems to be going off like it did last year and the year before." Again only one-half of the plot was weighed. Similarly in 1892 damage is recorded on Plot 8a. The first mention of damage to Plot 2 in the note-book was in 1894. There is, however, a statement in the printed Report of 1890, that, in spite of its good yield, "Plot 2 as usual looked at first extremely bare. Plot 8a was very patchy indeed."

Examination of the yields year by year about this period indicates that the damage to the barley crop set in rapidly. The method adopted in 1889 and 1890 of discarding the bad half of Plot 8 and weighing only the good half makes it impossible to institute a quantitative comparison, but at any rate it shows that the damage had by then become serious on that plot. The yields of Plots 2 and 5, which had kept about level with those of 3 and 6 respectively, began to part company for Plot 5 in 1890 and for Plot 2 in 1892, suggesting that either the minerals or the higher yields had hastened

[1] Annually for the first 5 years, then from 1882 onwards and biennially to each half in alternation. See p. 350.

the setting in of acidity. This may, however, not be a real effect but only a variation in the soil such as caused the bottom half of Plot 8 to show the harmful effects before the top half did.

Seeing that both Plots 5 and 8 received nearly the same total quantity of sulphate of ammonia, though Plot 5 had it in annual doses and Plot 8 in biennial doses, it is not surprising that both should have shown the symptoms of acidity at approximately the same time: Plot 8 had actually received a little more and suffered perhaps a little earlier.

Once the change became apparent it developed rapidly, and within a few years the yields had fallen very low; finally the crop almost disappeared. Even the weeds went also, with the single exception of spurrey (*Spergula arvensis*), and this flourished. The fall was greatest on Plot 2 without minerals. If there is some doubt whether the minerals hastened the setting in of acidity there is no question that they mitigated its worst effects. Plots 5 and 8, with minerals, continued to produce harvestable crops, even though they might only be of 2 or 3 bushels per acre, long after Plot 2 was a mere mass of spurrey.

In the whole range of British field experiments there has probably been nothing more striking than this row of barley plots where Plots 1, 2, and 3 stand next each other (Fig. 26).

The cause of the trouble, however, was not discovered. The explanation came from another quarter. By a curious coincidence, a similar collapse of yield on the sulphate of ammonia plots was happening at the same time at the Rhode Island Experimental Station at Kingston, Rhode Island, and Dr. Wheeler, who was then director, in a masterly investigation, traced it to the acidity derived from the acid radicle in the sulphate of ammonia.[1]

Although the barley seems to have disappeared from these acid plots at Woburn, it has not really done so. The seed

[1] H. J. Wheeler, Rhode Island Experiment Station, *Third Annual Report*, 1891, p. 31. This was followed up in later Reports.

germinates and the seedlings duly appear. The root system, however, is very stunted, the roots are very thick and carry only a few root hairs, the leaves quickly become reddish at the tips and at the base of the sheath, then they change to yellow, and soon they cannot be distinguished in the thick growth of spurrey that covers the whole plot and attains a height of about 9 inches. From April onwards no barley can be seen. Careful search among the spurrey shows, however, that the barley is still alive and going through its normal stages. Although the plant is only 8 or 9 inches high, it ripens and produces tiny heads of diminutive grain at about the same time as the normal plants on the adjacent plots. These Lilliputian plants are very curious; they are now being studied in detail; they are probably the smallest barley plants ever produced.

The three symptoms, patchiness, restricted root system with marked lack of root hairs, and stunted growth, are now recognised signs of soil acidity, enabling the soil expert to pick out at once those fields which require fuller examination with the view of supplying lime.

In spite of the fact that the plant is profoundly affected by the acidity, certain characters show little, if any, change, at any rate in the early stages where growth is still sufficient to allow the grain to be harvested. Neither the percentage of nitrogen in the grain nor the ratio of grain to total produce is appreciably different on the acid plots from what it is on the others, although the yield may only be 2 or 3 per cent of the normal.

The Effect of Lime.

In 1897, when it was recognised that the falling-off of yield was due to acidity, the plots were subdivided and parts were treated with lime. No soil examinations were made, but samples were taken, and these have recently been examined by Dr. Crowther whose results are set out in Chapter XXII.

The simplest effects are produced by a dressing of 1 ton per acre on the plot receiving also complete minerals (Plot 5aa). For a period of some 8 or 10 years after application (1905) [1] this raised the yield to the level of the corresponding nitrate of soda plot (Plot 6), but then appeared signs of falling-off. A second dressing, also of 1 ton per acre, was therefore given (1916), and this kept the yield at the nitrate of soda level till 1926 when the experiment was discontinued (Fig. 27*a*).

More complex effects were produced by some dressings of 2 tons of lime per acre. The first dressings of 1897 had given results as described above, but the second dressings of 1912 behaved rather differently. They raised the yield well above that of the corresponding nitrate of soda plot (Plot 6), and this superiority persisted for 2 or 3 years: then, however, the yields fell approximately to the level of the nitrate of soda plot and stayed there to the end.

The initial effect suggests some decomposition of soil materials by the lime, such as the well-known hastening of the decomposition of organic matter with production of more available nitrogen compounds.

Small dressings of lime at the rate of 5 cwt. per acre produced rather remarkable effects, shown in Fig. 27*b*. For several years they kept the yield well above that for sulphate of ammonia alone. Three dressings were given between 1909 and 1912, amounting in all to 15 cwt. of lime per acre, and although, owing to variations in yield from year to year, it is not possible to say how long the effects of the lime did persist in the soil, it is safe to say that they lasted for at least 10 years. These small dressings certainly seemed to be more economically utilised than the larger ones, and in any question of compensation for liming the quantity of the dressing and the " lime status " of the soil should apparently be taken into account in assessing the rate to be allowed per

[1] The dressings were given in March and had no effect in the first year.

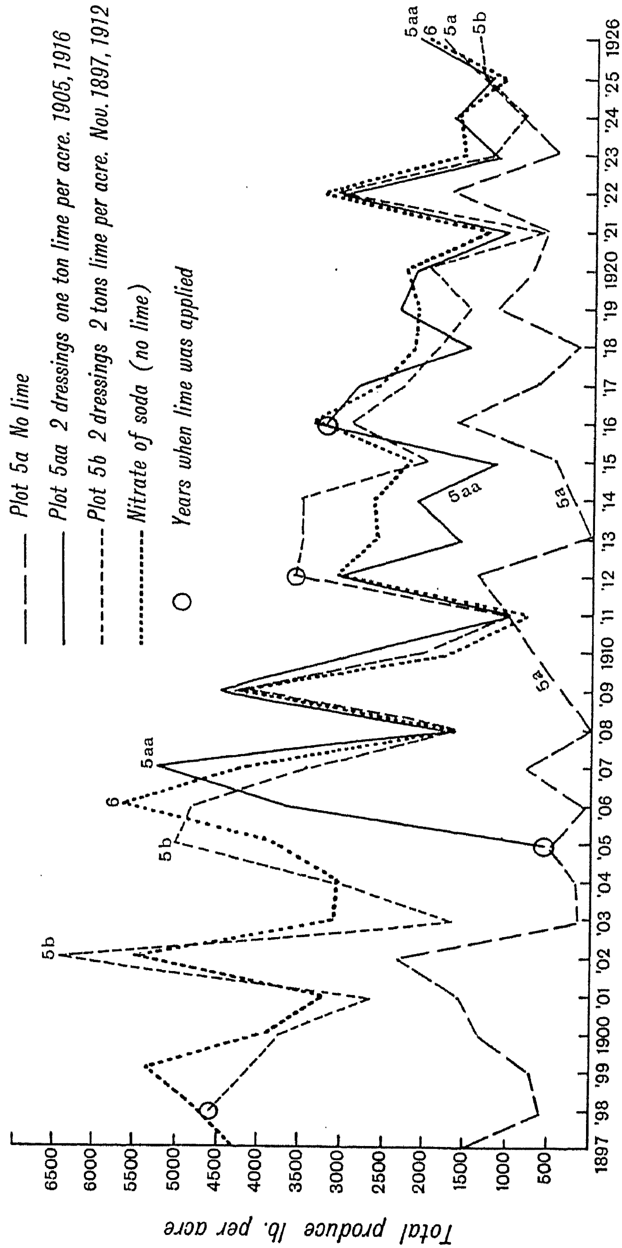


FIG. 27*a*.—Effect of lime in large and in small doses on the Plots receiving sulphate of ammonia and minerals.

ton of lime given. A ton of lime lasts longer on a very acid soil than on a nearly neutral one.

One other plot was subdivided and limed, Plot 4, which receives mineral fertilizers only and no nitrogen. Although this plot is somewhat acid (its *p*H value was 5·4 in 1932 barley), the lime had only a small effect such as might be given by an increase in the amount of available nitrogen. Much later and near the end of the period lime was also added to part of two of the nitrate of soda plots, which are

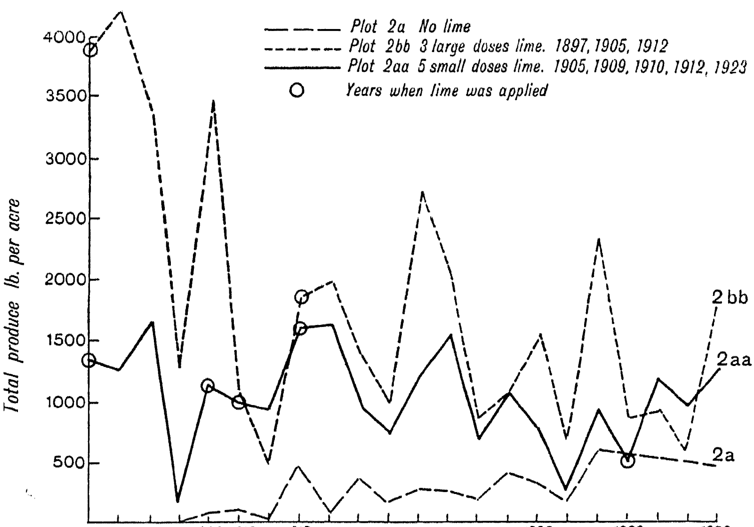


FIG. 27*b*.—Effect of lime in large and in small doses on the plots receiving sulphate of ammonia only.

also somewhat acid (*p*H 5·8), and this also raised the yield in the second year but not afterwards.

The results for wheat are of the same general character as those for barley, but the effects of the acidity were later in developing, owing to the circumstance that wheat is less sensitive than barley.

Further, the mineral fertilizers appeared to have a more pronounced effect in delaying the setting in of acidity than on barley.

The wheat plots showed another interesting result. During the first few years of acidity, and before it had become too pronounced, the sulphate of ammonia was unusually effective. During the 6 years preceding the signs of acidity (1886–91) the wheat on the sulphate of ammonia plots, 2 and 5, had only once (in 1889) done so well as on the nitrate of soda plots, 3 and 6. In 6 of the next 7 years, and before the yields began to fall, the yields given by sulphate of ammonia were as good as those given by nitrate of soda, if not better. Then came the fall (Fig. 28). The plots testing residual effects showed the same phenomenon ; for a time those manured with sulphate of ammonia in the preceding year, and on which therefore the effects of acidity would probably be somewhat reduced by the loss of salts through winter rainfall, gave remarkably higher results than in either the earlier or the later years.

The barley results are different ; they show no tendency towards temporary improvement on any of the sulphate of ammonia plots relative to the nitrate of soda plots.

Assuming the wheat result to be really due to the sulphate of ammonia, there seem two possible explanations.

We may assume that the marginal degree of acidity, i.e. the degree that just precedes the injury, definitely stimulates the growth of plants : this is supported by the patchy appearance of a crop just beginning to suffer, when some of the plants grow unusually well and others almost fail. Alternatively, the additional growth may be associated with the fact that one of the most important fungus diseases of wheat at Woburn at the present time, Take-all (*Ophiobolus graminis*), is severely checked by soil acidity, and over a certain range of acidity the wheat plant can still grow well while the fungus cannot. Unfortunately, the records do not show whether the disease occurred at the time so that we cannot test this possibility. A further possibility is that the soil acidity may retard nitrification in the autumn and so reduce the loss of nitrate during winter. There is also

evidence that ammonia may be more effectively and rapidly utilised by plants than nitrate ; in normal conditions plants

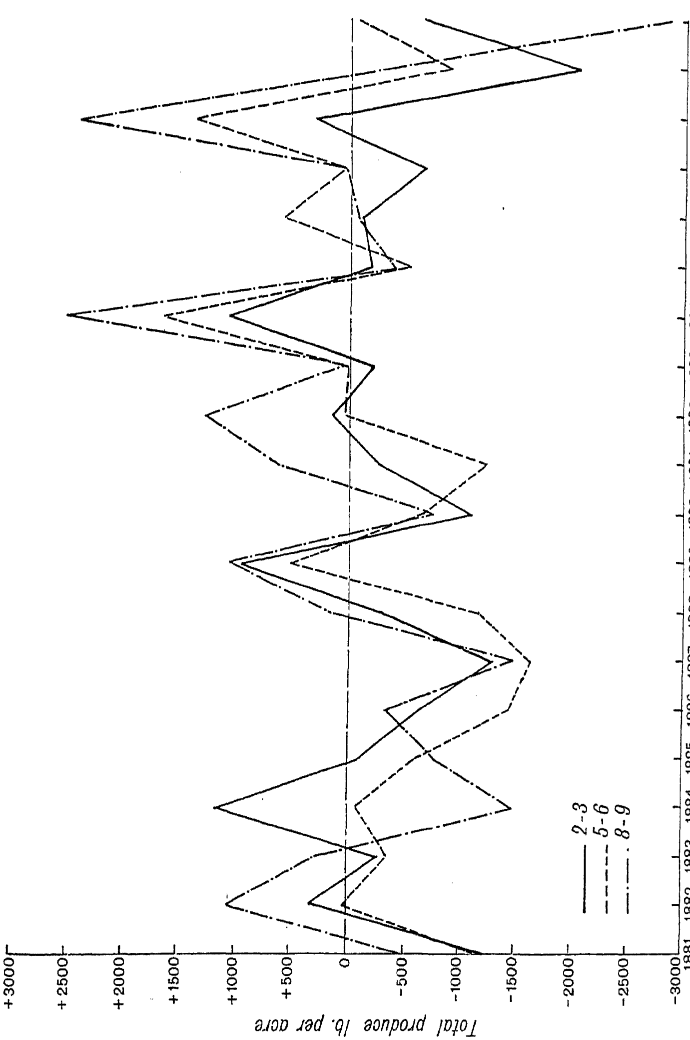


FIG. 28.—Apparent temporary stimulating effect of soil acidity on wheat. Differences between yield from sulphate of ammonia and from nitrate of soda ; where the points lie above the horizontal line, sulphate of ammonia gave the higher yield.

have but little opportunity of obtaining ammonia because of the rapid nitrification by bacteria : under these marginal

conditions nitrification may be sufficiently slowed down to give the plant this opportunity.

Whatever the cause, this stimulation effect (assuming it to be real) persists only for a few years. Afterwards the wheat suffers, though not as much as the barley.

Farmyard Manure as Compared with Artificial Fertilizers.

The original scheme of experiment included two farmyard manure plots receiving respectively about 4 and 8 tons per acre (about 53 and 105 lb. nitrogen), and the plan was widened in 1882 so as to test residual effects. The four plots continued till 1887 when the two plots concerned with the smaller dressing were unfortunately discontinued. The results are in consequence too few to justify detailed discussion, nevertheless they suggest certain points of interest.

For the 10 years over which the experiment ran the increments of total produce in cwt. per acre are given in Table 71.

TABLE 71.—INCREMENTS GIVEN BY SINGLE AND DOUBLE DOSES OF FARMYARD MANURE.

	Increments over Unmanured (1 and 7).			Over Minerals only (4).		
	Single Dose, 53 lb. N.	Double Dose, 105 lb. N.	Ratio.	Single Dose, 53 lb. N.	Double Dose, 105 lb. N.	Ratio.
First 5 years (1877–81):						
Barley .	4·37	12·24	1 : 2·8	6·28	14·16	1 : 2
Wheat .	3·46	10·87	1 : 3·1	1·25	8·66	1 : 7
Second 5 years (1882–86):						
Barley .	7·54	19·54	1 : 2·6	9·44	21·44	1 : 2
Wheat .	9·31	19·45	1 : 2·1	9·54	19·67	1 : 2

The result differs from that obtained with nitrate of soda in that the second increment is as effective as the first,

if not more so, thus justifying the standard practice of using rather large dressings of farmyard manure but small dressings of artificial fertilizers.

A second difference came into prominence as the years went on: the farmyard manure maintained its effectiveness; there was no such falling-off as with nitrate of soda or sulphate of ammonia. One part of nitrogen in farmyard manure gave consistently some 20–25 parts of total produce and 10 of barley grain and some 18–25 parts of total produce and 6–8 of wheat grain from the beginning almost through to the end of the experiment; while nitrate of soda proved less and less effective as time went on, especially on the barley (p. 244).

These two differences in action make it impossible to assign any definite equivalent value to the nitrogen in farmyard manure when the nitrate of soda is set at 100. The values obtained range from 23 in the first 15 years of the experiment (using Plot 6, 41 lb. nitrogen, as the basis of comparison) to 70 in the final 15 years when the effectiveness of the nitrate of soda had fallen considerably. For practical purposes the earlier low value is of more importance than the later high ones; it is confirmed by the 1932 experiments on kale where, however, the comparison was made with sulphate of ammonia. The figures are:—

Wheat, first 15 years	25 (nitrate of soda).
Barley, first 15 years	24 (nitrate of soda).
Kale, 1 year (1932)	22·4 (sulphate of ammonia).

This figure represents only the effects in the year of application; if residual effects could be taken into account it would be increased.

Residual Effects of Fertilizers and Manures: (a) Farmyard Manure.

Several of the Woburn experiments deal with the residual effects of farmyard manure.

The first set of data were obtained from 1882 onward, when Plots 10 and 11, which for 5 years had received 4 tons and 8 tons per acre respectively of farmyard manure, were halved, and for the next 25 years one half received no manure

Residual effect of 5 dressings of farmyard manure. Excess of yield of grain over unmanured Plots 1 and 7.

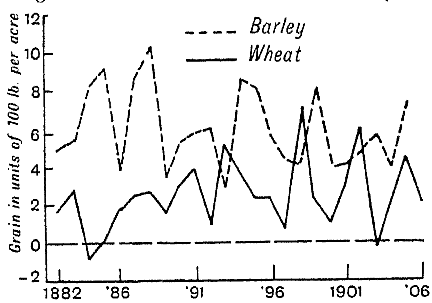


FIG. 29.—Dressings of 8 tons per acre.

while the other continued to receive its former dressings, Plot 10b for 6 years only and Plot 11b until 1906.

The results are given on pages 352–9 and shown in Figs. 29–30. Plot 10a had in the preceding 5 years received in all about 20 tons farmyard manure containing approximately

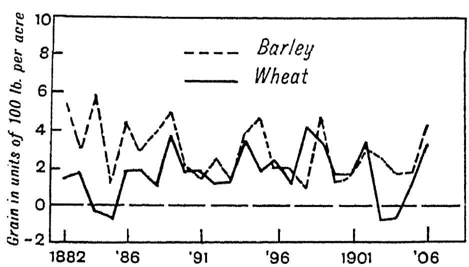


FIG. 30.—Dressings of 4 tons per acre.

265 lb. nitrogen. Using the method of estimation described on page 287, the crop had during this time recovered 23 lb., leaving a balance of 240 lb. stored in the soil or lost. For the first 5 years after discontinuing the farmyard manure there was an actual rise in yield, due probably to good seasons, on all the plots including the unmanured. In the succeeding

5-year periods the yields on Plot 10a continued to fall but they never reached the level of the unmanured plots, instead they kept roughly parallel to them. It seemed as if the 20 tons of farmyard manure had permanently changed the soil.

Plot 11a had received in the preceding 5 years 40 tons per acre of farmyard manure containing about 525 lb. nitrogen; and its yield, while falling, remained always above that of 10a, which indeed it showed no sign of approaching.

Both plots kept step with each other and with the unmanured plot for 25 years, and the differences in yield corresponded with the differences in the original manuring. Unfortunately the experiment was then discontinued; it would have been most interesting to see how long the yields would have continued superior to the unmanured plots and whether, and if so where, they would become stabilised. But the whole result may be simply due to soil irregularities —as is shown to be possible on page 159.[1]

A similar persistence of farmyard manure is, however, shown on Hoos Field at Rothamsted. One of the permanent barley plots, 7–1, received farmyard manure annually, from 1852 to 1871, while an adjoining plot received no manure. From 1872 onwards 7–1 also has been left without manure. Its yields have fallen, but have always been well above those on the adjoining unmanured plot. The line between the plots

[1] If the effects are to be attributed to the farmyard manure the nitrogen balance sheet becomes very striking :—

	Plot 10a, lb. per Acre.		Plot 11a, lb. per Acre.	
Total nitrogen supplied in farmyard manure, 5 years, 1877–81		265		525
Nitrogen removed in crops, excess over unmanured . . .				
Direct effect, 5 years, 1877–81 .	23		80	
Residual effect, 25 years, 1882–1906	200	223	420	500
Balance not accounted for:				
lb.		42		25
per cent.		16		5
percentage recovery				95

is so sharp that one can hardly explain the result as a soil irregularity. It is possible that repeated annual dressings of farmyard manure have special effects in the soil apart from the supply of plant food.

Assuming that a long persisting effect had been produced at Woburn as at Rothamsted, the source of nitrogen for the crops presents some difficulty. One cannot suppose that the nitrogen compounds in farmyard manure are so nicely graded in stability that equal quantities are decomposed in successive years. It is more probable that the nitrogen is taking part in a regular cycle, presumably micro-organic, part of the nitrate formed by decomposition being assimilated and built up into tissue protein which, on the death of the organism, breaks down to give nitrate once more. The soil conditions being fairly stable on these continuously cropped plots, the cycle may be expected to go in much the same way each year, delivering a fairly uniform amount of nitrate for crop production. Similar conditions appear to occur on the rain gauges at Rothamsted.[1]

Presumably the presence of the straw in farmyard manure accounts for the persistence of the added nitrogen in the soil. In the green-manuring and the sheep-folding experiments, where no straw was added, the added nitrogen did not persist, but was lost fairly quickly.

Straw differs chemically in two important respects from the green crops: it contains less protein, and considerably more lignin. This substance is not readily decomposable in the soil, and it protects some of the cellulose from decomposition. It appears to play an important part in forming soil humus.

(b) Sulphate of Ammonia and Nitrate of Soda.

The Rothamsted experiments have usually been taken as showing that neither nitrate of soda nor sulphate of

[1] E. J. Russell and E. H. Richards, *J. Agr. Sci.*, 1920, vol. 10, pp. 22–43.

ammonia left any residue of manurial value in the soil: whatever was missed by the growing crop was supposed to be lost. At Woburn the results were different, and from the outset it appeared that both nitrate of soda and, until the soil became acid, sulphate of ammonia, left something in the soil which benefited the succeeding crop. The omission of nitrogenous fertilizers alternately from one half and then from the other half of Plot 8 and Plot 9 did not, as at Rothamsted, bring down the yields to the level of the plot continuously without nitrogen. The results are shown in Figs. 31–32; the latter shows the marked difference caused by the acidifying effect of the sulphate of ammonia.

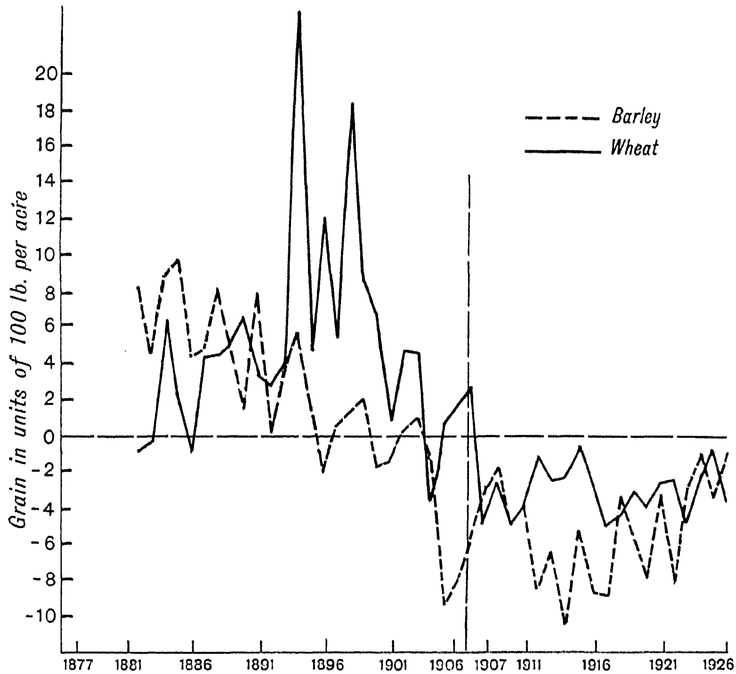
Over the whole period the average residual effect has been in cwt. grain per acre per annum:—

	1882–1906.		1907–1926.	
	Barley.	Wheat.	Barley.	Wheat.
Nitrate of soda	4·04	1·45	1·70	0·59
Sulphate of ammonia	5·62[1]	2·81[1]	—	—

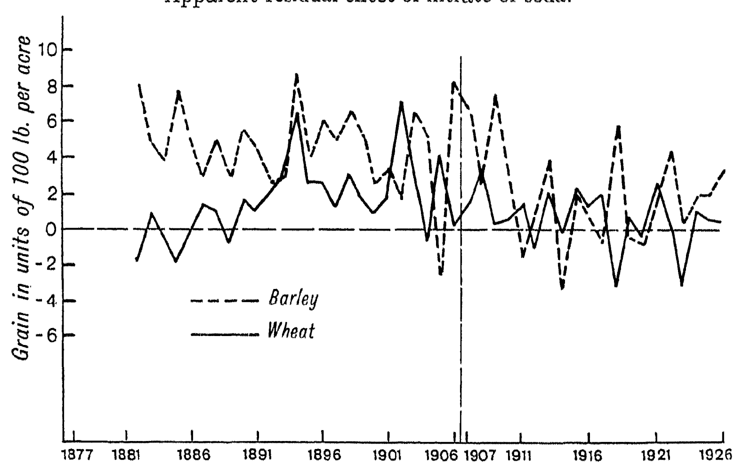
It is difficult to understand these results. The green-manuring experiments in the same field seem to show clearly that nitric nitrogen does not persist in the soil over the winter: and yet these residual effects appear to be quite definite. Some doubt, however, is thrown upon them by the circumstances that nitrate of soda had no clear residual effect on wheat, which should have shown it equally well. The nitrate of soda certainly had some persisting effects on the barley plots, for in the years 1928 to 1933 when manuring was discontinued the plots formerly receiving nitrate of soda stood out distinctly superior to those that had received none, in spite of 2 years of intervening fallow (1927 and 1928). Sulphate of ammonia apparently left residues on both the wheat and barley plots, but as shown on page 159 the possibility of soil irregularity makes the results uncertain. By a curious coincidence the Rothamsted plots, which indicate that there

[1] 1882–91.

Apparent residual effect of sulphate of ammonia.



Apparent residual effect of nitrate of soda.



FIGS. 31 and 32.—Increments of yield on plot receiving nitrogen in the previous year over yield on plot receiving no nitrogen.

is no residual nitrogen, are also open to objection,[1] so that even now the question whether nitrate of soda or sulphate of ammonia leave any residues in the soil cannot be regarded as solved. The new methods of field experimentation have the great advantage that they give definite answers and do not leave problems in this unsatisfactory position.

[1] See R. A. Fisher, *Phil. Trans.*, B, 213, 1924.

CHAPTER XV.

SOIL DETERIORATION UNDER CONDITIONS OF CONTINUOUS CROPPING.

Frequent Growth of Cereals on the Same Land.

MODERN conditions often make it desirable to keep away from fixed rotations, and fears have been expressed that if this is done the land must suffer. The growth of more than two white straw crops in succession is commonly considered in Great Britain to be bad farming. Now that the quota scheme is encouraging the growth of wheat in England, the question is often asked how far continuous cropping can be practised in modern conditions.

Both at Woburn and at Rothamsted the evidence is quite clear: cereal crops can perfectly well be grown in succession for years without risk of injury to yield or soil provided weeds can be kept down, and provided also that serious soil pests or diseases such as Eelworm, Foot Rots (*Fusarium*), Take-all (*Ophiobolus*), etc., do not accumulate in the soil. No difficulties in regard to any of these diseases occurred on any of the three best-known fields under continuous cereals at Rothamsted, Woburn, and Sawbridgeworth (Mr. Prout's farm) respectively. On some farms on the chalky soils of Norfolk and the southern counties farmers who have gone in for mechanisation are already experiencing trouble with *Ophiobolus* and *Fusarium* after very few years of continuous wheat cropping. What is the cause of this difference? It is too early to give a complete explanation, but apparently the difference lies in the amount of chalk

present in the soil; this seems to be favourable to the Foot Rots and Take-all, and there was no great amount of it either at Rothamsted or Sawbridgeworth, and none at all at Woburn.

It is hoped to carry out further investigations on this disease problem, but in the meantime it is safe to conclude that given freedom from disease, suitable manuring, and sufficient cultivation to keep down weeds, cereals can be grown on the same land for several years in succession though after a long period deterioration sets in.

Deterioration of Yield under Continuous Cropping. Counteraction by Fertilizers and Farmyard Manure.

Figs. 33 and 34 show[1] that the yields rose for the first years on all the plots but then fell, but the fall was less

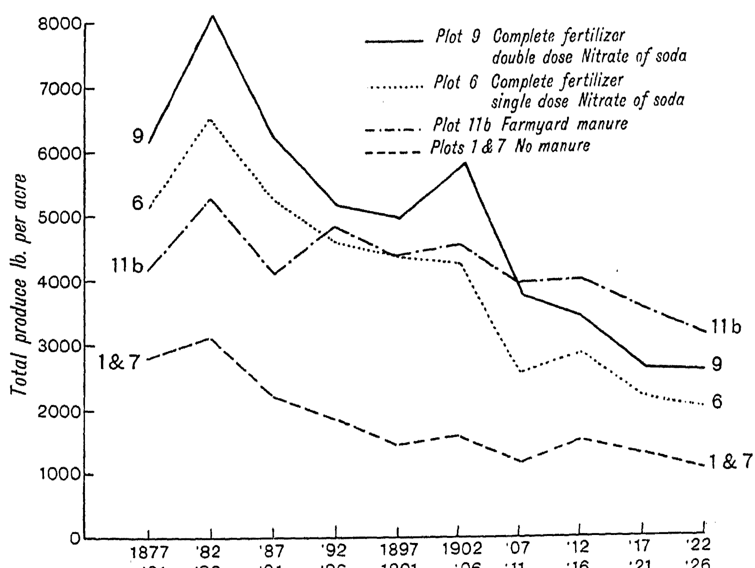


FIG. 33.—Yields of total produce. Barley, lb. per acre: 5-year averages 1877-1926.

[1] The details for all plots are given in Tables 120–4.

marked on some plots than on others. It became more pronounced after 1906 when the manuring was changed, but we cannot say whether this is the result of reduced manuring or of some adverse factor that was assuming more and more importance as the years went by. Both unmanured plots show the further fall in yield, however, as also does Plot 4, on which the change in manuring would not be likely to have much effect. This deterioration of yield is not due to a

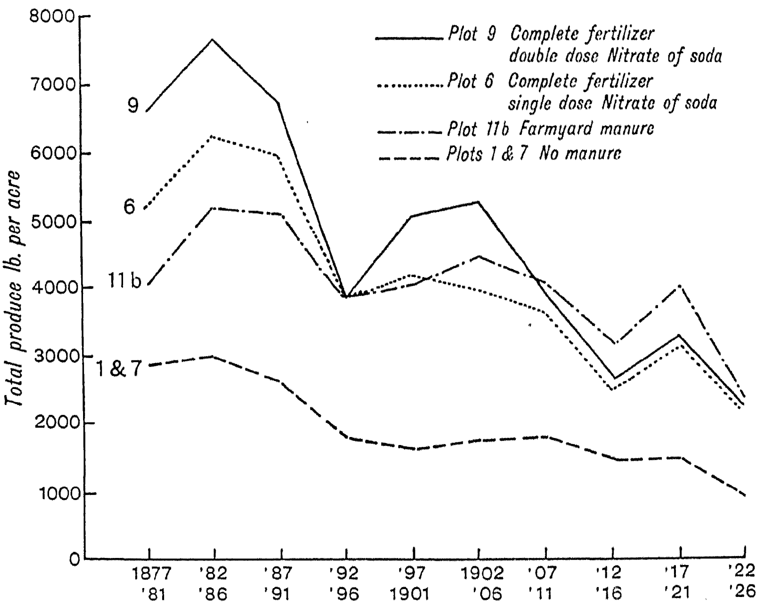


FIG. 34.—Yields of total produce. Wheat, lb. per acre: 5-year averages 1877-1926.

peculiarity of the Woburn soil, for it occurs on the entirely different Rothamsted soil, and although no strict comparison is possible owing to the difference in period of time there is a general similarity in result.

It is difficult to say why a crop supplied with complete fertilizer should fail to maintain its yield when grown year after year on the same land. The deterioration is not entirely associated with the continuous cropping, for it is seen

also on the rotation plots both at Rothamsted and at Woburn.

An adequate investigation is made impossible by the change of manuring that took place after 30 years, and which greatly reduced the value of the work without conferring any compensating advantage. One lesson that can be drawn from Woburn is that once a long-continued experiment is started its plan should not be altered.

The best examination possible in the circumstances has been made, and is set out in Chapter X., but the results are not commensurate with the great amount of labour involved.

The outstanding result is that for the first 30 years only one of the treatments maintained yields: farmyard manure applied at the rate of about 8 tons per acre per annum. The level of yield is lower during the last 20 years, but this may be associated with the smaller dressing. No other treatment kept up the yields so well. The complete artificials, using nitrate of soda as the source of nitrogen, come next, and for wheat they are not far behind farmyard manure, but for barley they are less effective. At the higher dressing of nitrate of soda the curve for artificial fertilizers shows more resemblance to that for farmyard manure, and it is possible that at equal doses of nitrogen, i.e. 105 lb. nitrogen per acre as nitrate of soda, the difference attributable to organic matter might have been only small. This possibility is of some interest because the percentages of carbon and of nitrogen in the soil of Plot 9 have fallen, unlike those on the plot receiving farmyard manure. There was no evidence for the statement often made to the effect that nitrate of soda used alone tends particularly to exhaust the soil, although of course it is less effective in absence of potash and superphosphate than when they are present. The rates of deterioration are no greater on the plots receiving nitrate of soda alone than on the unmanured, in spite of the higher yield and the greater draft on the soil for the mineral constituents.

The rates of deterioration for 1877–1906 are :—

		Wheat. Bushels per Acre.	Wheat. Percentage.	Barley. Bushels. per Acre.	Barley. Percentage.
Nitrate of soda	Plot 3a .	·334	1·56	·703	2·25
No manure	Plot 1 .	·410	3·22	·701	3·79
No manure	Plot 7 .	·286	2·01	·425	2·34

Of the two groups of fertilizer constituents, nitrogen was the more important constituent for maintaining the yields

Effect on plant growth of nitrogen added in nitrate of soda and in farmyard manure. Increments of grain and of total produce (over plots with nitrogen) per lb. nitrogen applied in fertiliser.

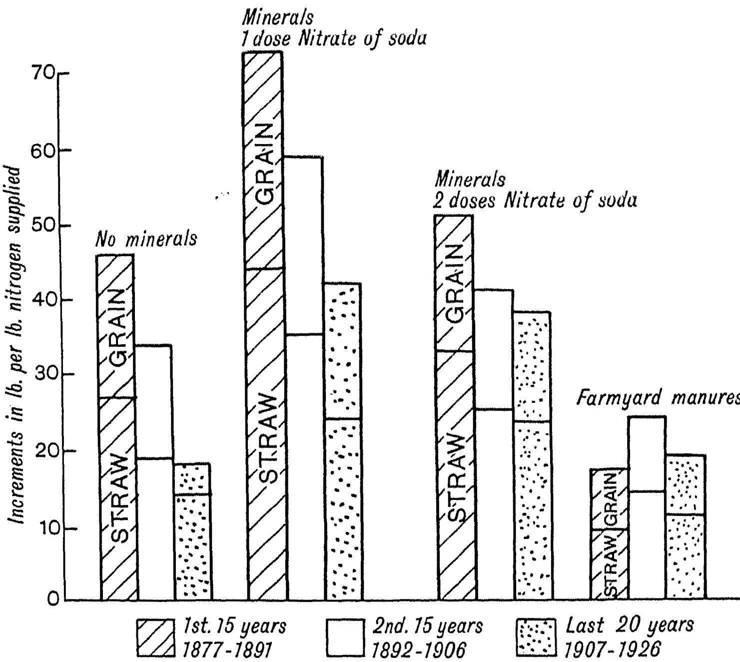


FIG. 35*a*.—Barley.

of wheat, and the mineral fertilizers for maintaining those of barley [1] (Figs. 2–7). This difference between wheat and

[1] On page 146, Mr. Cochran sets out evidence which, however, is very slender, showing that superphosphate may be the more potent constituent for reducing the deterioration of barley yields, while it apparently increased both yields and deterioration of wheat. Potash, on the other hand, apparently reduced the deterioration of wheat but not of barley.

barley leads to some rather striking results. The nitrogen retained its effectiveness on the wheat crop and yielded increments of total produce and of grain which kept up fairly well to the end. But it did not maintain its effectiveness for barley; here the increments fell off in the later years (Fig. 35). Thus in the early years 1 lb. of nitrogen added as nitrate of soda in a complete fertilizer gave an increment of some

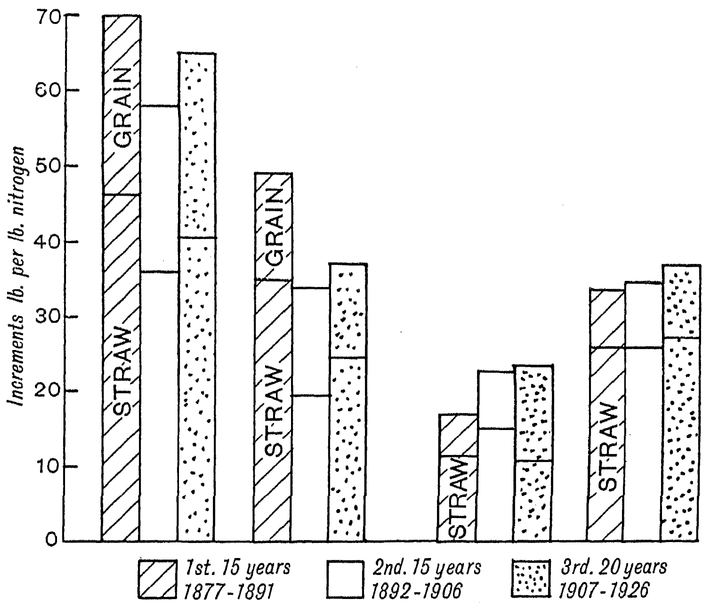


FIG. 35*b*.—Wheat. The columns correspond to those for barley, and the headings are the same.

73 lb. of total produce in the yield of barley and of 70 lb. for wheat; in the last 20 years, however, the increments were 65 lb. of wheat, but only about 40 lb. of barley. Again, in the case of wheat the basal yield without nitrogen fell to a greater extent than the increments given by nitrogen, so that the percentage increments increased and the increase was more marked on Plot 9 with the double dose of nitrogen than on Plot 6 with the single dose. After 1906, when the

nitrogen dressings were halved, the percentage increments dropped also.

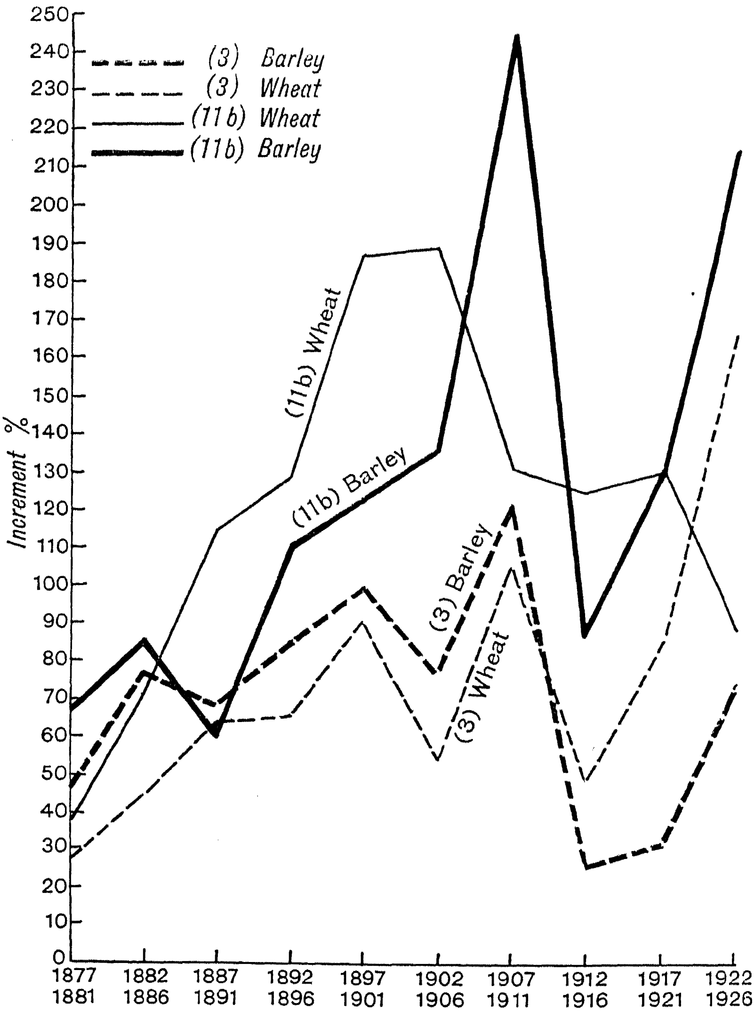


FIG. 36.—Percentage increments of wheat and barley grain for nitrogen applied as farmyard manure and as nitrate of soda (single dose) without minerals.

For barley the percentage increments rose to approximately the same extent as for wheat on the plots without

minerals, but where these were given the rise of percentage increment was markedly less (Figs. 36, 37).

As a result of this relative steadiness in action of farmyard manure the effectiveness of its nitrogen, when that of

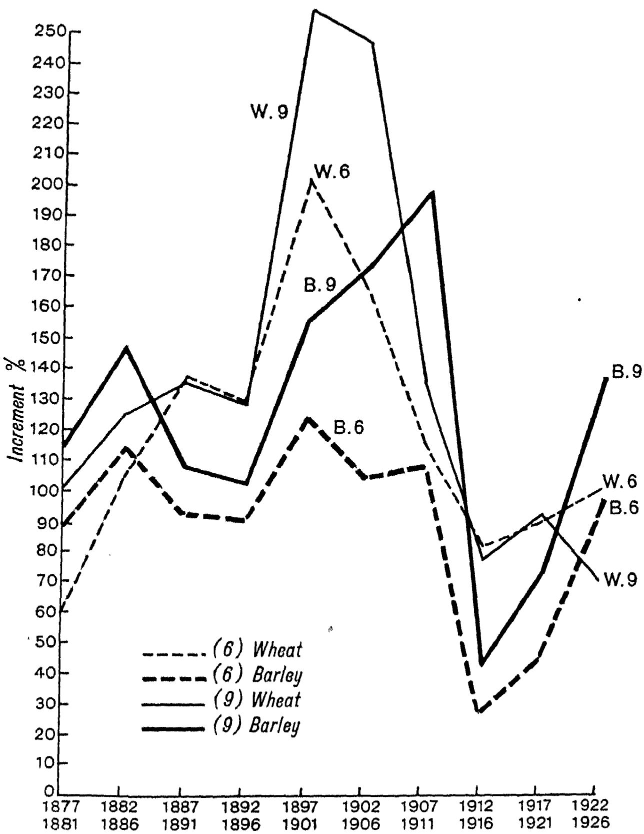


FIG. 37.—Percentage increments of wheat and of barley grain for single and double doses of nitrate of soda, showing progressive increase for wheat until about 1901. Barley behaves somewhat differently.

nitrogen in nitrate of soda is put at 100, appears to rise throughout the whole period for barley and up to a certain point for wheat also (Table 72).

Unfortunately, as happens not infrequently with the

TABLE 72.—INCREMENTS GIVEN BY NITRATE OF SODA AND BY FARMYARD MANURE.

Grain per lb. Nitrogen Supplied.	First 15 years. Barley.	First 15 years. Wheat.	Second 15 years. Barley.	Second 15 years. Wheat.	Last 20 years. Barley.	Last 20 years. Wheat.
Farmyard manure	8	6	10	8	11	8
Nitrate of soda	29	24	24	22	18(*a*) 15(*b*)	25
Effectiveness of nitrogen in farmyard manure when that in nitrate of soda = 100	28	24	42	36	67	32

Total Produce per lb. Nitrogen Supplied.	First 15 years. Barley.	First 15 years. Wheat.	Second 15 years. Barley.	Second 15 years. Wheat.	Last 20 years. Barley.	Last 20 years. Wheat.
Farmyard manure	18	18	25	24	27	25
Nitrate of soda	73	70	59	58	42	65
Effectiveness of nitrogen in farmyard manure when that in nitrate of soda = 100	24	25	43	42	65	39

(*a*) Plot 6, but dressing halved. (*b*) Plot 9, but same dressing as previously on Plot 6.

Woburn data, there is a disturbing factor which cannot be eliminated and which therefore makes detailed discussion impossible. A serious complication was brought into the experiment by consistently making later the date of application of the nitrate of soda and sulphate of ammonia.

The mean dates were :—

	Permanent Wheat.	Permanent Barley.
1880–1886	April 2nd.	April 22nd.
1887–1896	May 1st.	May 8th.
1897–1906	May 12th.	May 23rd.
1907–1916	May 25th.	May 30th.
1917–1926	June 8th.	June 15th.

There is evidence from other experiments that late dressings do not act in quite the same way as early ones and part

of the supposed deterioration may be due to this. However, a falling-off in effectiveness of the added nitrogen also occurs at Rothamsted where the date of application has not been systematically altered, and this suggests that deterioration is an effective factor.

Closely associated with this deterioration of yield, and perhaps the immediate cause of it, is a diminished uptake of nitrogen by the plant. This was only to be expected on the plots receiving no nitrogen. For the first years the barley took up nearly 30 lb. per acre of nitrogen from the soil: in the last 5 years only 7 lb. from the unmanured and 12 lb. from that receiving mineral manures alone. Here it might be argued that the nitrogen was not there for the plant to take up, but a similar, though proportionately smaller fall occurs on the plots annually fertilized with nitrate of soda.

In the 15 years, 1877–91, there was but little deterioration of yields, and the barley on Plot 6 took up some 62 lb. nitrogen per acre per annum; this being 34 lb. more than on Plot 4 without nitrate of soda, a utilisation of nearly 90 per cent. In the last 5 years, 1922–6, when deterioration had become marked, however, the barley took up on an average only about 20 lb. nitrogen per acre, being about 9 lb. more than on Plot 4, a utilisation of only about 45 per cent (Fig. 38).

Apart from its size the crop itself showed but little change. The straw of course became shorter as the years went by, but the proportion of grain to straw did not fall until towards the end of the 50 years, and as shown later, the fall may be apparent only and not real. The weight per bushel of grain, and the weight of 1000 corns also fluctuated about the same levels throughout and showed no regular tendency to fall, except again right at the end of the experiment. Such small changes as occurred were more pronounced for barley than for wheat. The nitrogen content of the barley grain did not tend to move either up or down.

The nitrogen taken up by the plant was just as effective

in promoting plant growth at the end of the experiment as at the beginning. For each lb. of nitrogen assimilated some 90 lb. of total produce was obtained both in the early years of the experiment and in the last years. No investigations

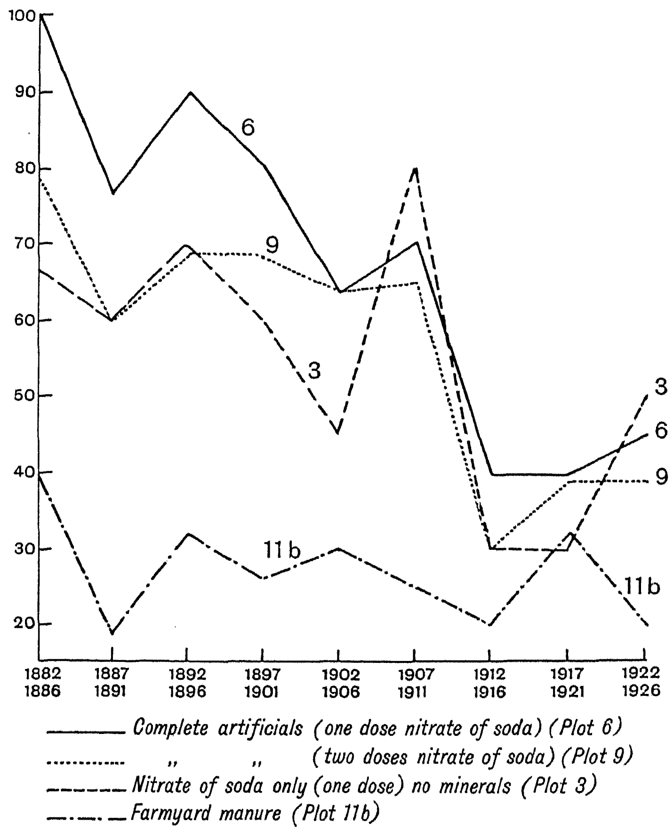


FIG. 38.—Percentage recovery of nitrogen from added fertiliser. Barley.

were made to ascertain whether the deterioration of yield is associated with changes in the plant other than those attributable to poverty in nutrients.

On several occasions during the course of the experiments samples of soil were taken from certain of the plots, and these

have been analysed at Rothamsted under Dr. Crowther's supervision (Chap. XXII.). A detailed study of the carbon and nitrogen content of the soils was made by A. Walkley in 1933. At the beginning of the experiment in 1876, the carbon and nitrogen contents were both high: during the experiment they fell, excepting only on the plot receiving farmyard manure.

The figures are, as percentages of air-dry soil, approximately as follows:—

	At beginning, 1876.	At end, 1926. Farmyard Manure Plot.	At end, 1926. Artificials only and Unmanured.
Carbon . .	1·48	1·5	1·0
Nitrogen . .	0·155	0·15	0·09

As between the various artificial manure treatments, there was little to choose. There was also little difference between the wheat and the barley plots, and such differences as exist are not obviously connected with cropping or manuring. They may easily be attributed to soil variation. The carbon figures are rendered somewhat uncertain from the fact that fragments of coal are found on some of the plots, and there is no means of knowing whence it came or how much is present. The nitrogen figures offer a safer means of estimating the changes in the amount of organic matter, and these are plotted in Fig. 39.[1]

On the other hand, there is no evidence of any difference in the nature of the soil organic matter as the experiment progressed, nor as between one plot and another. The ratio of carbon to nitrogen in the soil remains about 9·7 with no indication of any difference between the unmanured plot and that receiving farmyard manure, or between the early and the later years of the experiment.[2]

The falling-off in the quantity of organic matter in the soil presents obvious similarities to the deterioration of crop

[1] For details see Table 105.

[2] Some of the wheat plots give a higher ratio, but it is on these that the particles of coal are found.

yield, but there is no close connection. No connection can be traced, for example, between the carbon or nitrogen contents of the soils at the end of the period and the mean yields for the preceding 10 years.

The replaceable bases in the soil also diminished during the 50 years of the experiment, but these changes, as would

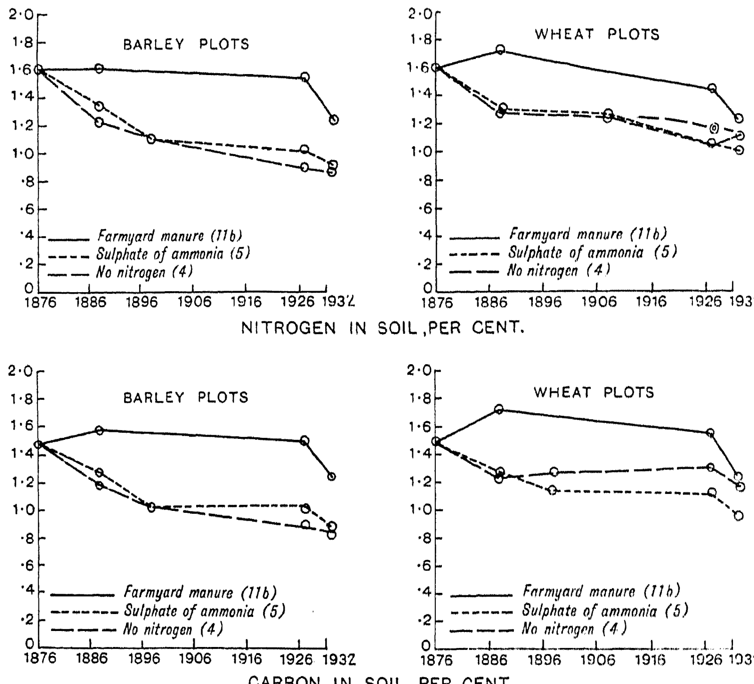


FIG. 39.—Changes in carbon and nitrogen content in soil of various plots.

be expected, are fairly clearly related to the manuring. The data are given in Table 110 (p. 329) and fully discussed in Chapter XXII.[1]

On all plots there is a falling-off that shows some relation to the deterioration. It is most marked on the acid plots;

[1] E. M. Crowther and J. K. Basu, *J. Agr. Sci.*, 1931, vol. 21, p. 689. The agricultural significance of these changes is discussed by E. M. Crowther in *J. Roy. Agr. Soc.*, 1932, vol. 93.

it is very clear, though less pronounced, on the plots without nitrogenous fertilizer; it is least where farmyard manure is given or complete artificial manures with nitrate of soda as the source of nitrogen. Complete data for other bases are lacking. These are present in small quantities only, and magnesium is the chief one, but so far as the results go they indicate changes in the same direction as for calcium.

Effect of Fallowing.

Whatever the cause of the deterioration, it is for a time completely overcome by a bare fallow. After the 50 years were over the plots were left fallow for the two seasons, 1927 and 1928. In 1929 they were again sown, but no manures were applied.

The effect of the 2 years' fallow was remarkable. The yields on most of the plots rose to the levels of the first 5 years (1876–81) when no sign of deterioration had yet appeared. The only exceptions were the sulphate of ammonia plots that had become acid: against acidity fallowing has obviously little effect. The yields of barley grain in cwt. per acre are given in Table 73.

TABLE 73.—EFFECT OF FALLOWING IN RESTORING PRODUCTIVENESS AFTER CONTINUOUS CROPPING. YIELDS OF BARLEY, CWT. GRAIN PER ACRE.

	No Manure. 1 and 7.	Minerals only. 4.	Nitrate of Soda only. 3a and b.	Nitrate of Soda, Minerals. 9.[1]	Farmyard Manure. 11a.
Last 5 years of continuous cropping, 1922–6 . . .	2·7	3·9	4·2	5·5	11·0
After 2 years' fallow—1929 . . .	9·4	10·5	14·5	17·2	16·9
First 5 years, 1877–81, deterioration not evident . . .	10·9	10·0	15·9	16·6	16·8

[1] Years without nitrate of soda—1882–6 period.

The striking benefit of fallow lasted only 1 year; after that the yields dropped considerably; in 1930, they were down to the level of the 1922–6 period, and in 1931 and 1932 they were still lower (Tables 74 and 75).

TABLE 74.—YIELD CWT. PER ACRE AFTER TWO YEARS OF FALLOW, 1927 AND 1928. BARLEY.

Plot.	Total Produce.					Grain.				
	Average 5 years, 1922–6.	1929.	1930.	1931.	1932.	Average 5 years, 1922–6.	1929.	1930.	1931.	1932.
1	9·4	22·0	13·0	16·5	2·7	3·0	9·5	6·1	5·0	0·2
7	8·3	21·3	10·7	13·4	5·3	2·4	9·2	5·1	4·0	0·6
4a	9·5	22·8	13·3	21·1	2·7	3·5	9·9	6·3	7·2	0·3
4b	12·4	25·2	13·4	14·9	1·9	4·3	11·2	6·7	3·8	0·2
2a	1·8	3·8	1·5	—	—	0·9	1·2	0·6	—	—
2b	11·5	26·5	12·7	15·6	2·8	3·8	11·4	6·3	4·1	0·5
2aa	8·6	17·4	12·8	17·0	3·5	2·2	7·1	6·4	4·7	0·6
2bb	11·6	20·8	9·6	14·1	3·1	4·1	9·3	4·7	4·0	0·6
3a	14·2	35·1	12·3	15·4	7·3	4·7	16·2	5·9	3·7	1·5
3aa	12·0	15·6	9·0	15·3	5·8	3·8	7·8	4·6	5·2	1·3
3b	11·9	27·7	11·3	16·5	6·0	3·7	12·8	5·3	4·4	1·0
3bb	10·8	18·2	7·7	13·7	6·4	3·6	8·6	3·8	3·9	1·2
5a	7·3	6·8	3·2	—	—	2·6	2·6	1·1	—	—
5b	14·9	25·7	14·9	19·0	7·9	5·6	11·3	7·8	5·5	1·4
5aa	17·2	16·0	16·6	15·5	2·2	6·7	7·2	8·3	3·8	0·3
6	17·8	29·7	15·9	18·4	9·2	6·9	14·4	7·8	4·7	2·0
8a	1·1	1·0	1·2	—	—	0·4	0·6	0·3	—	—
8b	1·0	3·4	1·2	—	—	0·4	1·8	0·4	—	—
8aa	—	31·9	13·2	28·5	20·3	6·1	13·4	6·6	10·1	6·7
8bb	—	32·9	14·4	37·2	23·4	4·5	14·5	7·4	13·8	8·0
9a	22·5	33·8	15·6	34·7	27·7	8·3	16·0	8·0	11·7	9·1
9b	15·5	37·9	15·9	32·2	23·4	5·5	17·2	8·0	10·2	11·3
10a	13·9	20·3	10·5	31·3	9·6	4·7	10·1	3·9	12·0	1·2
10b	9·2	7·2	3·0	11·6	1·2	2·8	2·7	1·4	2·5	0·0
11a	16·2	30·4	16·3	34·3	24·1	6·1	14·4	7·1	10·4	2·0
11b	28·0	33·7	18·3	30·7	17·7	11·0	16·9	9·5	9·0	4·4

The rise in wheat yields as the result of the fallowing was not quite as marked, except on the plots receiving farmyard manure (11b) and minerals only (4), both of which reached the levels of 1877–81. Plot 4 remained superior to 1 and 7 throughout the period 1929–32, confirming the indications of the period 1917–26 that the minerals were now benefiting the wheat.

TABLE 75.—YIELD CWT. PER ACRE AFTER TWO YEARS OF FALLOW, 1927 AND 1928. WHEAT.

Plot.	Total Produce. Average 5 years, 1922–6.	1929.	1930.	1931.	1932.	Grain. Average 5 years, 1922–6.	1929.	1930.	1931.	1932.
1	8·3	17·1	4·7	8·6	13·8	2·5	6·0	0·6	1·4	2·8
7	8·3	12·1	1·9	5·4	11·5	2·5	4·6	0·3	1·7	1·9
4	10·2	26·1	10·9	13·2	16·1	2·9	9·7	1·4	3·6	2·9
2a	1·7	0·8	0·2	6·1	5·6	0·1	0·1	—	1·5	—
2b	10·0	2·8	1·5	18·4	13·2	2·9	0·6	0·1	5·8	3·5
2aa	9·8	2·4	0·2	8·8	11·2	2·5	0·9	0·0	2·1	2·7
2bb	9·8	7·0	3·7	7·9	12·5	3·0	2·8	0·1	1·9	3·5
3a	22·4	15·2	6·5	7·5	11·8	6·7	6·9	1·6	2·8	2·6
3b	17·1	11·5	6·4	6·1	9·5	5·7	4·9	1·8	2·3	2·1
5a	13·2	14·2	1·8	24·0	20·0	3·3	5·8	0·2	6·5	4·0
5b	17·1	19·2	5·0	13·7	16·5	4·9	7·0	0·8	3·1	4·3
6	19·0	16·6	7·9	16·4	17·5	5·9	6·7	2·7	4·9	3·9
8a	4·4	4·2	3·2	11·8	2·4	1·0	1·4	0·1	2·9	—
8b	2·0	4·1	1·9	13·9	4·3	0·5	1·5	0·1	4·3	—
8aa	14·0	10·0	1·4	22·1	11·6	3·4	4·1	0·1	7·2	2·2
8bb	8·1	11·9	1·2	13·9	14·9	2·4	4·9	0·0	5·6	4·0
9a	19·7	22·7	6·8	13·5	17·9	5·0	9·3	2·1	3·5	3·4
9b	10·6	19·9	6·1	18·0	20·2	2·8	9·0	1·6	4·9	3·7
10a	21·5	11·9	7·5	7·7	15·9	6·3	5·0	1·9	2·5	4·6
10b	14·1	8·9	6·1	7·2	12·4	4·6	2·9	1·5	3·1	3·4
11a	20·7	23·1	7·8	14·1	19·6	5·5	2·8	2·8	4·3	5·2
11b	21·3	32·4	14·8	17·3	25·2	5·5	11·5	3·9	3·8	6·2

During this 2 years' fallow there seems to have been a heavy loss of organic matter from the soil of the plots previously receiving farmyard manure, though not from the other soils. The data for the barley plots are given in Table 76.

TABLE 76.—PERCENTAGES OF CARBON AND OF NITROGEN IN AIR-DRIED SOIL.

Manuring.	Plot.	Carbon. 1927, before Fallow.	Carbon. 1932, after Fallow and further Cropping.	Nitrogen. 1927, before Fallow.	Nitrogen. 1932, after Fallow and further Cropping.
Farmyard manure .	11b	1·50	1·23	0·151	0·123
Complete artificials .	6	1·05	0·98	0·109	0·100
No manure . .	1	0·96	0·93	0·094	0·095

Assuming the samples really represented the plots, the loss of carbon would be of the order of 8000 lb. per acre.

Effect of Rotation of Crops.

The deterioration is not confined to land carrying the same crop continuously. It occurs also on the land under a rotation. At the other end of Stackyard Field an experiment is carried on which includes both wheat and barley. The results, summarised in Table 77 and discussed in Chapter XIII, page 196, show that deterioration of yield has occurred there also and to a more marked extent than on the continuous wheat or barley. Detailed comparison between the continuous and the rotation is not possible because the manuring has been different, the rotation plots having received much less manure than those under continuous wheat or barley.

Since 1926 the yields of wheat and barley on the rotation plots have not fallen further and indeed in the last few years some fairly good crops have been obtained. This may indicate a certain degree of recovery, but it may also be due simply to good seasons, for a rise has also been shown by wheat after green manure crops on Stackyard field :—

Yield of Grain, cwt. per Acre.					
Wheat after Green Manure.		Rotation Series.			
		Wheat.		Barley.	
1912-1920	7·2	1911-1926	12·0	1911-20	10·0
1921-1926	3·4	1928	10·8	1927	7·1
1927-1930	2·8	1929	9·8	1930	13·8
1931-1934	4·6	1932	10·1	1931	13·0
		1933	15·1	1934	16·4

No comparison can be made with the permanent plots as they were fallowed during the two seasons 1927 and 1928.

At Rothamsted the deterioration is quite definite both in the continuous and on the rotation plots, though again no quantitative comparison is possible because the manuring is different, and Agdell Field, on which the rotation experiments are made, is about half a mile distant from the Broadbalk and Hoos Fields on which the wheat and barley are grown continuously. The results are given in Table 78.

TABLE 77.—COMPARISON OF YIELDS OF WHEAT AND OF BARLEY GROWN ON THE CONTINUOUS AND THE ROTATION PLOTS OF STACKYARD FIELD, WOBURN.

Period.	No Manure.	Nitrate of Soda, Grain, cwt. per Acre.				Organic Manure,[1] Grain, cwt. per Acre.			
		Mean Yields.		Nitrogen in Manure, lb. per Annum.		Mean Yields.		Nitrogen in Manure, lb. per Acre.	
	Continuous.	Continuous.	Rotation.	Continuous.	Rotation.	Continuous.	Rotation.	Continuous.	Rotation.
					Barley.				
1878–85	12·0	22·8	24·2	42	None	20·1	23·0	105	None
1886–97	7·6	19·0	19·9	42	23	17·9	18·3	105	23
1905–10	5·7	13·8	20·3	21	46	18·2	23·3	82	46
1911–26	3·9	8·3	—	21	43	14·3	12·0	82	43
					Wheat.				
1878–85	8·6	16·9	22·8	42	39	14·1	22·6	105	39
1886–97	6·8	15·0	19·1	42	None	14·1	19·2	105	None
1905–10	6·2	12·2	11·3[2]	21	None	12·5	11·0[2]	82	None
1911–26	4·3	10·0	—	21	None	11·5	13·0	82	None

[1] Farmyard manure on the continuous barley; sheep droppings on the rotation.

[2] Mustard preceded wheat instead of clover.

TABLE 78.—YIELDS OF WHEAT AND OF BARLEY IN CONTINUOUS AND ROTATIONAL CROPPING. GRAIN, CWT. PER ACRE. (AVERAGES IN THREE PERIODS.) ROTHAMSTED.

Wheat.					Barley.				
	Unmanured.		Manured.			Unmanured.		Manured.	
Year.	Continuous. Bdbk. 3.	Rotation. Agdell 5 and 6.	Continuous. Bdbk. 6.	Rotation. Agdell 1 and 2.	Year.	Continuous. Hoos 1 o.	Rotation Agdell 5 and 6.	Continuous. Hoos 4a.	Rotation. Agdell 1 and 2.
1851–75	13·6	28·6	25·5	32·8	1853–1877[1]	18·9	30·4	49·0	45·2
1879–1903	11·0	24·5	20·7	34·4	1881–1905[1]	9·0	17·0	33·1	29·7
1907–1927	9·0	15·2	17·7	20·3	1909–1929[1]	10·3	11·0	32·1	19·8

The 1931 wheat has been omitted from the averages, being almost a failure, due to lack of germination or frost damage on Agdell.

The Woburn results further show that the deterioration is not prevented by additions of small quantities of organic matter. During part of the time the rotation plots received every fourth year a small dressing of 3 to 4 tons per acre of farmyard manure, and 2 years thereafter the roots were folded by sheep receiving a small ration of cake or corn. Unfortunately the scheme of manuring changed so much that the effects of the various dressings cannot be assessed, but the total effect of the additions was inadequate to prevent deterioration. On the green-manure plots a crop of mustard or tares was ploughed in annually, but deterioration went on apparently as rapidly as on the unmanured plots.

A similar inability of clover residues to prevent the effects of deterioration is also shown on Agdell Field, Rothamsted, which has been in the four-course rotation since 1848 ; roots, barley, clover, wheat (Table 79).

[1] Only the years when barley was grown on the rotation plots have been used in this comparison. Barley was grown seven times during each of the first two periods and six times during the third.

TABLE 79.—AGDELL FIELD ROTATION EXPERIMENTS, ROTHAMSTED, SHOWING DETERIORATION EVEN WHEN CLOVER IS GROWN.

	Yields of Wheat, Bushels per Acre.		Yields of Barley, Bushels per Acre.		Yields of Fodder Crops.		
					Roots, cwt. per Acre.		Clover-hay, cwt. per Acre.
	After Fallow.	After Clover.	In Fallow Rotation.	In Clover Rotation.	In Fallow Rotation.	In Clover Rotation.	
No Manure.							
First 5 crops[7]	34·5	29·6	37·2	35·9	55·5	29·1	52·9[4]
Second 5 crops	23·5	21·0	22·8	22·5	34·3[1]	19·2[1]	21·9[5]
Third 5 crops	23·5	24·2	15·9	13·7	22·4	8·6	6·9[6]
Fourth 5 crops	14·6	14·4	12·6	8·7	13·1	2·6	11·9
Minerals only, no nitrogen [2] (to roots only).							
First 5 crops	36·6	32·5	36·7	36·5	173·8	146·7	56·5[4]
Second 5 crops	28·1	30·0	24·0	28·0	188·3[1]	197·2[1]	55·2[5]
Third 5 crops	28·0	38·4	15·9	22·2	184·2	225·7	34·8[6]
Fourth 5 crops	19·6	21·6	15·8	22·7	132·5	186·9	34·4
Complete artificials [3] (to roots only).							
First 5 crops	35·9	35·3	47·3	48·4	283·4	240·8	61·8[4]
Second 5 crops	27·4	32·0	36·4	41·1	342·9[1]	354·8[1]	66·0[5]
Third 5 crops	32·1	36·4	24·1	29·2	415·4	372·6	30·8[6]
Fourth 5 crops	20·0	17·9	16·6	23·0	331·3	195·2	25·5

[1] Four crops only, 1868 crop failed.

[2] The manures supplied are: 528 lb. superphosphate (35 per cent); 500 lb. sulphate of potash; 100 lb. sulphate of soda; 200 lb. sulphate of magnesia.

[3] The above, and, in addition, 206 lb. sulphate of ammonia and 2000 lb. rape-dust per acre once in 4 years to the root crop only.

[4] One year only, 1850: in 1854, 1858, 1862 clover was sown but failed and beans were grown instead.

[5] Three crops, 1874, 1882, 1886.

[6] Three crops, 1894, 1902, 1906.

[7] For wheat: 1851, 1855, 1859, 1863, 1867 constitute the first period: successive 4 years form the other periods.

For barley: 1849, 1853, 1857, 1861, 1865 from first period.

For roots: 1848, 1852, 1856, 1860, 1864 from first period.

For clover: 1850 only in first period, beans in the other years.

It must not be thought, however, that rotation is without effect on soil productiveness. On the contrary, the levels of yield on the rotation plots receiving only little nitrogen are, as the Tables show, approximately the same as on the continuous plots receiving considerably more nitrogen. But just as the higher dressings on the continuous plots fail to prevent deterioration so does rotation by itself. No doubt a combination of farmyard manure with rotation would prevent the setting in of deterioration, as indeed it does in practice, and it would be interesting to know what level of dressings on the rotation plots would correspond with the annual dressings of 8 tons of farmyard manure on the continuous plots.

The facts in regard to deterioration may be summarised as follows :—

1. The amount of nitrogen taken up by the plant from the soil falls off very considerably as the years go by, and the amount of plant growth correspondingly diminishes.

2. The deterioration in yield, however, does not affect the processes within the plant. It does not alter the effectiveness of the assimilated nitrogen for producing plant materials, nor the proportion of material translocated to form grain, nor the percentage of nitrogen in the grain, nor the bushel weight of the grain. This last, however, may decrease when deterioration becomes very pronounced.

3. It does not occur, or only slightly, on the plots receiving about 8 tons farmyard manure per annum (about 105 lb. nitrogen per acre). It occurs to some extent when complete artificial manures are given ; it is more marked with incomplete or no manure ; and very pronounced on the acid plots.

4. It is accompanied by a fall in the amount of carbon, of nitrogen and of replaceable calcium and other bases in the soil, but it is not strictly parallel to any of these. On the farmyard manure plot there has been no deterioration and no loss of nitrogen. On the plots receiving no fertilizer there

has been marked deterioration and a notable loss of nitrogen. On the plots receiving complete artificial fertilizers the loss of nitrogen has been almost, if not quite, as great as on the unmanured plots and the deterioration measured in cwts. of grain per acre has been approximately the same; the percentage deterioration of yield, however, has been less. On the other hand, the loss of replaceable bases has gone in the same direction as the percentage deterioration on the plots without manure or receiving artificial manures only. The losses of bases have, however, been quite marked on the farmyard manure plots which show no deterioration.

5. It is temporarily overcome by fallowing, but after the first season the crops speedily fall back to their old low levels.

6. It is not peculiar to continuous cropping but is shown on the rotation plots also.

It is difficult to give a complete explanation because of the complication due to weeds. As soon as the crop yields begin to fall the weeds secure a hold on the land and are dislodged only with the greatest difficulty. They compete for light above ground, and for moisture and nutrients below ground, and so they still further depress a crop that has begun to fail. At harvest their stalks are caught up and weighed with the straw, so causing the ratio of grain to straw to fall below its true value. During the fallow period they are killed and the first crop after the fallow is free from their competition, but they speedily re-establish themselves in the later and poorer crops.

It seems impossible, however, to attribute the whole phenomena of deterioration to weeds, unless one assumes that the standard of cultivation of 1876–91 had never since been equalled, and that cultivation had steadily deteriorated and reached its lowest level of efficiency in the period 1922–6.

Another possibility is suggested by the old hypothesis, developed by de Candolle a century ago, that plants excrete from their roots something injurious to their own kind but not to plants of a different kind. There is no evidence for

this view, and in any case it seems to be ruled out by the fact that deterioration occurs on the rotation plots as well as on those continuously under one crop.

A further possibility is the accumulation of disease organisms. This may have been a factor at Woburn. One fungus disease (*Ophiobolus graminis*) is now a serious cause of loss, and unfortunately the crop notes do not show when it first appeared. But disease accumulations are at best only a partial explanation of the deterioration for they cause very little trouble at Rothamsted.

The most probable cause of the deterioration seems to be the exhaustion of some soil constituent necessary for full plant growth under field conditions. The fact that artificial fertilizers do not entirely stop deterioration shows that the failing element is neither potassium nor phosphorus; nor can it be nitrogen, since the increments given per lb. of nitrogen fall off as deterioration progresses. It is more difficult to decide whether deterioration is due to exhaustion of some minor essential element such as boron, or manganese, though spectroscopic examination of the ash of plants on the exhausted soil made by Mr. Hugh Ramage of Norwich suggested no lack of these substances. The probability is that the deterioration is associated with the exhaustion of the organic matter. Yet it is not easy to see why this should be. The soil is in good physical condition both at Woburn and at Rothamsted, and if the effect of the organic matter on plant nutrition were simply to supply nitrogen, it is difficult to understand why the artificial fertilizers should not produce the same effect.

Clearly it is not all forms of organic matter that act: neither rape cake nor ploughed-in mustard or tares, nor the excretions from folded sheep, nor small quantities of farmyard manure, served to prevent deterioration. Farmyard manure given in relatively large amounts came nearest to doing this.

It seems possible that the straw is the source of the

effective agent. Experiments show that undecomposed straw does not itself enhance soil fertility, but that during decomposition the lignin of the straw combines with protein to form humus. Whether the deterioration results from the loss of humus or of some of the other products of decomposition of the straw is not known. The loss of humus is only relative, and even on the most exhausted plots the carbon remains about 0·9 per cent and the nitrogen 0·09 per cent. There is no reason at all to suppose that this residual humus is more resistant or less effective for plant growth than the humus that has been lost. Indeed the two are chemically indistinguishable. If humus is the effective substance, we can only suppose that at these levels of humus content, the soil productiveness rises and falls with the percentage of humus present. But this is, for the present, only a possibility to be further examined by further experiments.

Even if humus were proved to be the effective substance, the mechanism of its action would still remain to be discovered.

This question of deterioration never assumed any practical significance in the days when the standard practice was the four- or five-course rotation, including a good dressing of farmyard manure once during the period, and the folding of sheep on the leys and often on the roots as well. Nor did it arise in market garden practice where growers were able to obtain cheaply large quantities of stable manure from towns. It has become important to market gardeners since the displacement of horses by motors in the towns cut off their supply of stable manure, and it affects the so-called "mechanised farmers" who maintain an area of arable land larger than corresponds with their head of livestock.

Experiments have been going on for some years at Rothamsted, and they are now started at Woburn, to discover whether straw can be usefully returned to the land in any other form than that of farmyard manure. Two methods are being studied in detail: the straw is rotted by the action

of micro-organisms, the method being the well-known Adco process based on the investigations of Hutchinson and Richards at Rothamsted ; and straw is ploughed into the land, the necessary food for the micro-organisms being added simultaneously as a dressing of artificial fertilizer. A comparison with farmyard manure is being made and in due course the results will be announced.

CHAPTER XVI.

THE EFFECT OF SEASON ON THE YIELDS OF WHEAT AND BARLEY.

THE yields have varied by as much as 50 per cent. Both wheat and barley tend to vary in the same way; a season that is good for one is good for the other, and *vice versa*. Wheat, however, is more variable than barley at Woburn (measuring the variability by the percentage annual variance described on p. 162), while on the heavier soil at Rothamsted barley is the more variable. A further difference between wheat and barley is that nitrogenous manures steady the yield of barley while minerals do not, while for wheat it was the mineral manures that steadied the yield and not the nitrogenous manures.

The larger part of the differences from year to year are due to differences in the weather conditions. Until recently there was no satisfactory method for studying these: a typical dry and a typical wet season were contrasted and the differences were attributed to the rainfall. The method is highly unsatisfactory, though in the hands of a shrewd observer it gives some information which, however, can never be entirely trusted. In recent years R. A. Fisher has worked out methods at Rothamsted for studying accurately the effects of any meteorological factor that can be expressed by figures. These methods were applied to the Woburn data by Miss Webster and by Mr. Cochran, with results set out in Chapter XI. The methods themselves are highly technical, but the underlying idea is not difficult. If the figures for the annual yields are plotted on a diagram, certain general trends can be seen. By use of these new methods a

smooth curve can be drawn through the scattered figures to "fit" them as well as is possible and thus to express the trend without the complication due to merely seasonal factors. Most of the points actually lie off the curve and

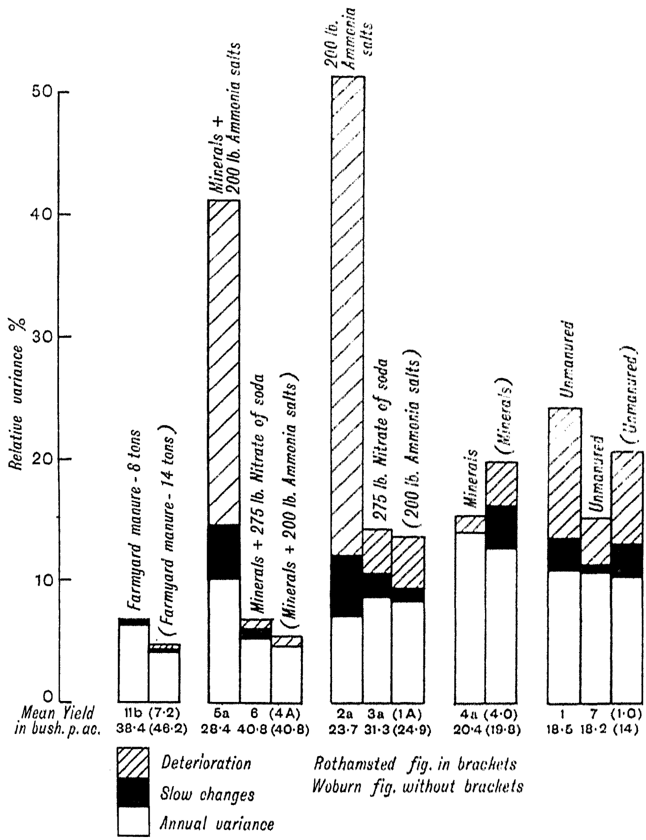


FIG. 40.—Comparison of causes of variation in Woburn (30 years) and Hoos Field (70 years) barley yields.

their distance away is a measure of the effect of the season. These distances can then be compared with meteorological data such as inches of rainfall, degrees of temperature, numbers of rainy days, etc., and the probability can be calculated that any apparent connection is simply due to chance.

A certain standard is set, and relations that satisfy the test are called "significant," which means that the odds are heavily against pure chance, and strongly suggest some causal connection. Relations that do not satisfy the test

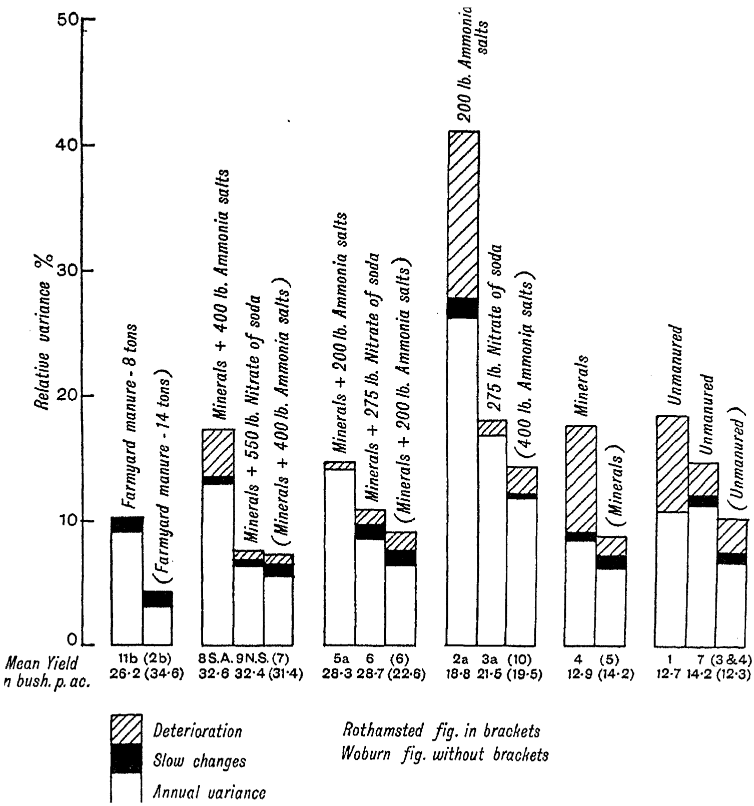


FIG. 41.—Comparison of causes of variation in Woburn (30 years, 1877-1906) and Broadbalk (67 years, 1852-1918) wheat yields.

must be regarded as speculative; there may be something in them but the figures do not prove it.

The smooth curves are given in Part II. (Figs. 11–13 (barley), 18–20 (wheat), p. 165). The results of the detailed examination are set out in the columns of Figs. 40 and 41, where the whole length of the column expresses the amount

of variation in yield, and the sections into which each column is divided show how much of the variation is to be attributed to annual causes such as weather, to steady deterioration, and to other slow changes respectively.

Probably the most interesting result of the whole examination has been to show that the manuring considerably influences the effect of season on the crop yield. Crops that receive the same kind of manuring behave similarly in different weather conditions; a wet spring, for instance, affects them all in the same way. For barley the treatments fall into four groups within which the effects of weather are similar :—

1. No nitrogen : Plots 1, 7, 4 (unmanured, minerals only).
2. Nitrogen only.
3. Complete artificials : Plots 6, 9.
4. Farmyard manure.

For wheat there is more similarity among the curves for the plots receiving artificial fertilizers, although the farmyard manure plot still stands out as something different.

A second interesting result is that the variation in yield (measured by the percentage annual variation) is least on the crops receiving farmyard manure or complete artificials, greater on the plots receiving incomplete manure, and still greater on the plots that have become acid. The complete manure and the farmyard manure not only give larger crops but steadier yields.

Difficulties arise, however, as soon as we try to find out what part the different factors play in causing these variations. The change in the manuring after 30 years on the plots receiving complete artificial manures and farmyard manure greatly reduces the value of the data and means that comparisons can be made only on the basis of 30 years instead of 50 years, which would have been a much better period.

On the Rothamsted wheat plots, where there has been no change in manurial treatment since 1852, a comparatively

simple effect of rainfall on yield was discovered by R. A. Fisher. He showed that the yield was affected by rain in every month of the year, whether the crop was actually in the ground or not, though in some months the effect was more marked than in others. Rainfall exerted considerable effects of the simple kind called "linear"; if 1 inch of rain above the normal in a certain month produced a certain effect, 2 inches produced double the effect. Some 30 to 40 per cent of the annual variation could thus be accounted for on some of the plots. The magnitude of the effects of rain above or below the normal depended on the kind of manuring. Neither barley nor mangolds, however, show these simple relations; the effect of rain is more complex, only a small part is "linear." At Woburn the effect is of this more complex order not only for barley but for wheat as well: for barley the more complex effects predominate both at Rothamsted and at Woburn; while for wheat they predominate at Woburn but not at Rothamsted.

At Woburn the maximum injury caused by the "linear" effects of rainfall to wheat yields is in October and in May or June, and the minimum injury is in January. At Rothamsted, on the other hand, the times of greatest injury are January and July with peaks of less injury or even benefit in October and April-May. The greatest injury to barley yields is done at both centres by October and April rainfall and the least by December and late July or early August rainfall. But it must be repeated, these "linear" effects are only a small part of the whole.

Miss Webster, adopting a method which allowed her to take account of more complex effects, was able to pick out the months in which excess of rain is most harmful and to give figures showing the order of damage done. The effects are not linear; if 1 inch additional rain reduces the crop by a certain amount, 2 inches does not reduce it by double the amount but by some other quantity.

Both methods agree in showing that the average rainfall

at Woburn, 24·2 inches per annum, of which 10·6 fall in the 6 months February to July, is ample for the needs of both barley and wheat as grown there, and any more is likely to do more harm than good. Woburn with its light sandy soil might ordinarily be regarded as liable to suffer in dry years. Actually the evidence points the other way; both for wheat and barley it is in the wetter rather than in the drier years that the crops suffer. The harmful effect is particularly pronounced in the spring months; the 4·5 inches falling in February, March, and April (approximately 1·5 inches in each) seem to be more than enough. The time of maximum injury and the extent of the damage depends on the manuring; inspection of the curves shows that for barley it occurred at the following periods:—

February–April,	Plots 1, 7, 4,	No nitrogen.
January and July,	Plots 6, 9,	Complete artificials.
Benefit in October, Injury in January.	Plot 11b,	Farmyard manure.

The 50-year curve for the unmanured plots is somewhat similar to the 70-year curve for the corresponding Rothamsted plot. The curves for the farmyard manure plots show resemblances though the effects seem to be rather greater at Woburn. The changes in yield in cwt. per acre caused by each additional inch of rain above the average falling in the various months are given in Table 80.

TABLE 80.—EFFECT PER INCH OF RAIN ABOVE THE AVERAGE FALLING IN VARIOUS MONTHS.

	Woburn (30-year period).	Rothamsted (70 years).
October [1]	+ 0·75	+ 0·40
February	− 1·65	− 0·70
June-July	− 0·40	+ 0·25

So far as these linear effects operate at Woburn, there is no evidence that they act differently from what they do at Rothamsted.

[1] Winter before sowing.

Both methods further agree in suggesting that in a wet spring farmyard manure makes matters worse rather than better, both for wheat and barley. Apparently its power to hold moisture, so valuable in many conditions, is either unwanted or positively harmful in wet spring conditions. But there is no evidence of any special advantage of farmyard manure over nitrate of soda or sulphate of ammonia in dry seasons—this is, of course, contrary to the usual statements. The Fisher method indicates that nitrate of soda mitigates the injury done by spring rain so far as the linear effects are concerned,[1] though the other method, which takes the more complex and the more dominating effects into account, indicates no greater benefit in wet than in dry springs.

The second method brings out, however, the interesting point that sulphate of ammonia is less effective than nitrate of soda in years when the spring is dry, but better in years when it is wet. The obvious explanation that the high rainfall has washed out the added nitrate of soda does not hold, for in general the nitrogenous fertilizer has not been applied till the end of April or early in May, i.e. after the period of

Increasing Nitrogen Dressings.			Change in Yield of Barley Grain, cwt. per Acre, caused by 1 inch Additional Rainfall.	
Nitrogen given, lb. per Acre.	Plot.	Average Yield, cwt. per Acre, 1877–1906.	February-March.	July.
		As Nitrate of Soda.		
0	1, 7, 4	8·88	− 1·10	− 0·60
42	6	19·34	− 0·60	− 0·95
42	3	14·73	− 0·70	− 0·70
84	9	22·17	+ 0·25	− 0·75
		As Farmyard Manure.		
105	11b	18·48	− 1·50	− 0·55

[1] The figures can be read directly from the curves, but for the convenience of the reader they are collected here.

rainfall in question. Its effect can therefore only be to remedy harm already done. Some residue of the previous year's dressings may survive after dry springs but not after wet ones: possibly also it is the sulphate of ammonia that varies in effectiveness while the nitrate of soda remains fairly steady. Farmyard manure has been effective in the dry springs, but it has been of much less value in the wet ones. The results for barley grain as read off from Miss Webster's curves are given in Table 81.

TABLE 81.—GAINS AND LOSSES OF BARLEY GRAIN ACCORDING AS THE RAINFALL IS AT ITS OPTIMUM OR TOO HIGH; CWT. PER ACRE.

	Plot.	Average Yield during the 29 years, 1878–1906.	Best March-April Rainfall (1·52 inches). Gain in Yield.	Worst March-April Rainfall (above 4 inches). Loss in Yield.
No manure	1, 7	8·5	1·25–2·50	1·00
Minerals only	4	9·6	4·00	2·00
Minerals + nitrate of soda	6, 9	20·8	3·50	2·50
Minerals + sulphate of ammonia	5, 8	14·9	2·00–3·00	1·00–2·00
Nitrate of soda alone	3	14·8	5·50	2·00
Sulphate of ammonia alone	2	11·6	1·75	1·00
Farmyard manure	11b	18·7	2·25	3·50

A parallel investigation on the wheat yields showed that for these also the average March-April rainfall (3·0 inches) was too high; the optimum value is about 2 inches.

It seems probable that these relations represent actual effects of nitrate of soda, sulphate of ammonia, and farmyard manure. For those who like a concrete illustration it can be obtained by arranging the years in order of wetness of April. The superiority of nitrate of soda over sulphate of ammonia is then seen to be much more marked in years of dry April than in years of wet ones. Further, the farmyard manure is much less effective when April is wet than when it is dry. These figures have no value except

for illustration, and the method could not be used to prove anything, but merely to illustrate facts established by more rigorous procedure. The same result is obtained for wheat; in dry years nitrate of soda is superior to sulphate of ammonia, while in the wet years it is either much less superior, or definitely inferior. Taking the whole 6-months period March-August, and arranging the years according as they are wetter or drier than the average, the results set out in Table 82 were obtained.

TABLE 82.—SUPERIORITY OF NITRATE OF SODA OVER SULPHATE OF AMMONIA AS MEASURED BY DIFFERENCE IN TOTAL PRODUCE (CWT. PER ACRE) ON COMPARABLE PLOTS. 20 YEARS, 1877–1896.

	Barley.			Wheat.		
	Wet Years.[1]	Dry Years.[1]	Mean all Years.	Wet Years.	Dry Years.	Mean.
Mean rainfall, inches, March-August	13·80	9·79	11·79	13·80[2]	9·79	11·79
Difference between Plots 3–2	1·8	5·0	3·4	−1·7	2·3	0·3
6–5	3·7	8·8	6·3	0·6	4·1	2·4
9–8	2·5	11·2	6·8	−4·7	2·8	−1·0

Early Summer Rainfall.

Another period when rainfall appears to have a marked effect on the yield of barley is during the third month of growth, 60 to 90 days after sowing. In this period (the average is May 24th to June 22nd) the plant is making its most rapid growth and therefore its heaviest demands on the soil moisture; apparently all of the average rainfall (2·23 inches) is needed. For most plots this quantity is enough, and any higher rainfall is harmful, but the two plots receiving the double dressing of nitrate of soda and sulphate of

[1] Ten years above average rainfall and 10 years below average rainfall respectively.

[2] Sulphate of ammonia superior to nitrate of soda.

ammonia, and making the heaviest growth, require more rain ; they respond to another half inch.

Deficiency of rain seems to be harmful, so that the average seems also to be the optimum rainfall (Fig. 17, p. 178).

The losses in cwt. of barley grain per acre for deficiencies or excesses of rain during this period read off from Miss Webster's curves are approximately :—

	Plot.	Deficiency of Rain.		Excess of Rain.	
		2 inches.	1 inch.	1 inch.	2 inches.
No manure . . .	1	2·2	0·5	1·0	3·5
Minerals only . .	4	2·8	0·5	0·5	3·0
Complete artificials .	6	5·0	1·5	0·5	3·0
(Nitrate of soda) . .	9	5·8	2·0	Nil	1·2
Complete artificials .	5	1·0	Nil	1·0	3·5
(Sulphate of ammonia) .	8	5·0	1·5	Nil	2·0
Farmyard manure .	11b	3·0	0·5	1·2	4·0

There are several differences from the preceding results. The effects are not linear. Two inches excess or deficit produce much more marked effects than double the effect of 1 inch. A marked effect is indicated for drought in June but not in the earlier months. There are, however, so few data that the actual values have no significance. Farmyard manure is shown as superior to nitrate of soda in the dry Junes ; in the dry springs this had not been the case.

The relative values of sulphate of ammonia and nitrate of soda do not agree with the previous results, the sulphate of ammonia at the lower dressings coming out superior to nitrate of soda in the years of dry June, both fertilizers being applied before the drought. The observed differences are insufficient to allow of any definite statement as to whether the fertilizers do differ in their respective relations to dry springs and dry Junes. The figures can be regarded only as indications to be tested when further data became available.

Relations between Yield, Sowing Data, and Rainfall about the Time of Sowing.

During the 30 years of the experiment the time of sowing the barley has varied from February 26th in 1898 to April 17th in 1901. No consistent effect on yield can, however, be detected. There is nothing to show that anything would have been gained by sowing earlier in the years of late sowing.

This is quite contrary to the well-known statement that early sowing is essential for good yields and for good quality. In point of fact the statement is not correct. Experience shows that barley sown in advance of what good practical judgment suggests, may suffer a severe check in early growth from which it never entirely recovers. Of course if sowing is delayed after this danger is passed, the yield suffers because the plant has insufficient time to complete its growth. The result indicates that those in charge of the experiment chose their sowing time well, and this fact probably explains why variations in rainfall at the time of sowing had but little influence on the result.

CHAPTER XVII.

THE NITROGEN CONTENT OF THE GRAIN OF BARLEY AND OF WHEAT.

No chemical examination of the grain was made during the course of the experiments, but fortunately samples from most of the plots were preserved and their nitrogen content and 1000 corn weight have been determined. During L. R. Bishop's extensive studies on barley at Rothamsted under the Institute of Brewing Research Scheme, he examined numerous samples of barley from Woburn, but beyond a rather high nitrogen content found nothing abnormal or exceptional about them. From his data the probable average composition of the grain can be estimated approximately as follows :—

APPROXIMATE PERCENTAGE IN DRIED GRAIN.

Nitrogen.	Total Nitrogen Compounds.	Hordein.	Glutelin.	Salt Soluble Compounds.	Hydrolysable or Extract-yielding Carbohydrates.
1·9	11·4	4·3	4·1	3·0	73

Nitrogen Content of Barley Grain.

The percentages of nitrogen in the barley grain from the more important plots are given in Tables 83, 84. The mean value 1·88 is distinctly above those obtained on good barley soils (usually about 1·3 to 1·5), but it is not exceptional for sandy soils. It is also higher than is obtained in rotation experiments at Woburn, but the data are too few to justify any general statement on this point :—

	1922.	1923.	1924.	1925.	1926.	Mean.
Permanent barley, Plot 6 .	1·65	2·07	1·44	2·29	1·96	1·88
Rotation barley	1·95	1·71	1·23	2·01	1·57	1·69

(Institute of Brewing series.)

In consequence of this high percentage of nitrogen the barleys from these Woburn plots have never appealed to maltsters, not even in the seasons during the 1880's when the permanent barley plots at Rothamsted were yielding good malting samples.

TABLE 83.—MEAN PERCENTAGES OF NITROGEN IN GRAIN OF BARLEY AND OF WHEAT, DRIED AT 100° C.

Plot.	1882–1886.	1887–1891.	1892–1896.	1897–1901.	1902–1906.	1907–1911.	1912–1916.	1917–1921.	1922–1926.	Mean. 1882–1926.
(a) Barley.										
1 and 7	1·98	1·82	1·87[1]	1·91	1·76	1·87	1·80	1·84	1·76	1·82
4a	1·74	1·69	1·70[1]	1·79[1]	1·63	1·75	1·74	1·82	1·80	1·74
2a	1·82[1]	2·16[1]	2·00[1]	2·25	2·06	1·69[1]	1·93	1·97	1·72[1]	2·00
3a	2·02[1]	2·00[1]	2·05[1]	2·20	2·00	1·98	2·06	2·06	2·06	2·05
5a	1·78[1]	1·85	2·06[1]	2·29[1]	1·86	1·76[1]	2·00[1]	1·90[1]	1·80	1·92
6	1·64[1]	1·81	1·92[1]	1·94	1·78	1·77	1·87	1·83	1·88	1·84
9ab with Nitr.	1·98[1]	2·15	2·07[1]	2·34	2·05	1·82	1·89	1·94	2·03	2·03
No Nitr.	2·06[1]	1·76	1·64[1]	1·84[1]	1·71	1·74	1·75	1·82	1·64[1]	1·81
10a	—	—	—	—	—	1·78	1·88	1·90	1·86	—
11a	—	—	—	—	—	1·82	1·87	1·91	1·98[1]	—
11b	2·09[1]	1·77	1·81[1]	1·84	1·74	1·77	1·73	1·96	1·90[1]	1·83
(b) Wheat.										
1 and 7	2·14[1]	2·06	1·95	2·09	1·90	1·83	1·96	1·92	1·76	1·95
4	2·18[1]	2·11	1·90[1]	2·21	1·98	1·87	1·97	1·95	1·86	2·01
3a[2]	2·42[1]	2·09	2·11	2·33	2·16	1·87	2·18	1·96	1·71	2·08
6	2·18[1]	2·02	2·21	2·28	2·14[1]	1·78	2·12	1·92[1]	1·84	2·04
11b	2·29[1]	2·13[2]	2·05	2·17	2·08[1]	1·99	2·02	1·94	1·92	2·05

Unlike the yield, the nitrogen content of the grain has shown no tendency to change as the years have passed by. This is rather different from what happened on Hoos Field, Rothamsted, where, as deterioration of yield progressed, the nitrogen content of the grain tended to rise. If this tendency existed at Woburn it would in any case be masked by the fact that the variety Plumage Archer, which has been grown for the last 5 years of the experiment, usually yields

[1] This figure is an average of less than 5 years.

[2] 3b from 1907–26.

grain of lower nitrogen content than the older sorts. The variations in nitrogen percentage from year to year are much less than those for yield, being only from 10 to 15 per cent, while those for yield are 40 to 50 per cent (Table 84).

TABLE 84.—NITROGEN CONTENT OF BARLEY GRAIN: VARIATION COMPARED WITH THAT OF YIELD.

	Plot.	No. of Years.[1]	Nitrogen per Cent in Dried Grain.		Percentage Variation.	
			Average.	Annual Variation.[2]	Nitrogen Content.	Yield.
Unmanured .	1	40	1·82	± 0·18	10	49
Minerals only, no nitrogen . .	4	37	1·74	± 0·21	12	39
Nitrate of soda only . .	3a	37	2·05	± 0·25	12	38
Sulphate of ammonia only .	2a	30	2·00	± 0·24	12	...
Minerals + nitrate of soda . .	6	39	1·84	± 0·27	15	26
Minerals + sulphate of ammonia . .	5a	35	1·92	± 0·25	13	...
Farmyard manure	11b	40	1·83	± 0·22	12	26

Effect of Manuring on Nitrogen Content of the Grain.

The average nitrogen content of the unmanured barley is 1·82 per cent. Mineral manures lowered it: nitrogenous manures raised it: in the mixture of manures with 41 lb. nitrogen per acre (Plot 6), these effects almost exactly counterbalanced, as also they did on the farmyard manure plot. The larger dressings of nitrogen (82 lb. per acre) on Plots 9 raised the nitrogen content of the grain to the level of the plot receiving 41 lb. nitrogen but no minerals: so that Plots 6 and 9 both suggested that the $3\frac{1}{2}$ cwt. super and 200 lb.

[1] Figures for different years are missing for different plots, so that for no plot is a complete series of figures over the 44 years, 1883–1926, available. The above figures are taken over all available years.

[2] S.E. of annual figures.

sulphate of potash[1] they received have counteracted the effect of 41 lb. nitrogen as nitrate of soda or sulphate of ammonia. The figures were nearly the same for the period 1882–1906 as for 1907–26. The Rothamsted result is substantially the same except that the farmyard manure plots fall into a different position. Nitrogenous manuring by itself has raised the nitrogen content of the grain, but when minerals are added the nitrogen content is brought down nearly to the level of the plot without nitrogen, and again 3½ cwt. super and 200 lb. sulphate of potash[2] have almost counteracted the effects of 43 lb. nitrogen in the fertilizer. A critical series of experiments conducted by the Rothamsted staff under the Institute of Brewing Research Scheme on certain barley-growing farms in various parts of the country gave similar results, except that the numerical values were lower (Table 85).

TABLE 85.—AVERAGE NITROGEN PERCENTAGE IN BARLEY GROWN UNDER VARIOUS CONDITIONS.

	Plot.	Woburn. 1885–1906.	Woburn. 1906–1926.	Rothamsted, Hoos Field.	Institute of Brewing Centres. Malting Barleys.
No manure .	1 and 7	1·83	1·82	1·47	1·47
Minerals only .	4	1·70	1·78	1·51	1·46
Nitrogen only .	2, 3b, 3a	2·06	2·00	1·67	1·50
Minerals + nitrogen, 41 lb. .	6	1·83	1·84[3]	1·54	1·47
Farmyard manure	11b	1·83	1·84[3]	1·84	—
Minerals + nitrogen, 82 lb. .	9	2·15	1·92[3]	—	—

There is no evidence of any lowering of the nitrogen content of the grain by nitrogenous fertilizer such as is not

[1] In addition 100 lb. each of sulphate of soda and sulphate of magnesia were given per acre, but there is no evidence that these influence the result.

[2] With sulphate of magnesia and soda, which probably do not much influence the result.

[3] Reduced dressing.

infrequently obtained when smaller dressings are given and the general level of nitrogen content is lower. Even the residues from the nitrate of soda have raised the percentages of nitrogen in the grain, as is seen in the following averages :—

No Nitrogen. Minerals only.	Nitrogen in Preceding Year only. Minerals only.	Nitrogen in Current Year Minerals also.
Plot 4.	Plot 9b.	Plot 9a.
1·74	1·81	2·03

Nor is there any evidence for the common statements that the nitrogen content is lowered by using sulphate of ammonia in place of nitrate of soda. The nitrogen content did not rise as the soil became more acid. On the other hand, liming somewhat lowered the nitrogen content in two pairs of plots, but did not affect it on the third (p. 186).

The effects are all small, however ; no scheme of manuring yet tested does much more than counteract the effect of the nitrogenous manure. As for all other crops so far examined, manuring increases the yield but hardly affects the quality ; and so long as the dressings raise the yield and do not cause lodging there is no reason to fear loss of quality, indeed a small improvement may be expected. But no marked change can be produced : the nitrogen content cannot by manuring be brought down to the level of the malting barley series. The nitrogen content is fixed mainly by the general soil and climatic conditions and, while it can be raised by manuring, it is not easily lowered ; there is, indeed, no way in which this can with certainty be accomplished.

Causes of Annual Variation in Nitrogen Content of Grain. Relation Between Nitrogen Content and Yield.

On all plots high yields were associated with lowered nitrogen content, each additional cwt. of grain reducing the nitrogen percentage by about 0·02 per cent.

Effect of Rainfall.

Rainfall has a simpler effect on the nitrogen content of the grain than it has on the yield. The curve of Fig. 32 where this effect is shown, satisfies the statistical tests of significance, while those of Figs. 11–14 and 18–20, dealing with yield, do not. The most critical rainfall period for nitrogen content is May, June, and July: indeed 1 inch of rain above the average at the beginning of June lowers the nitrogen content by about 0·10 per cent. Curiously enough this June rainfall, which is so important for nitrogen content, has little effect on yield, while the March-April rainfall, which depresses the yield, has little effect on the nitrogen content: if anything it tends to raise it.

The manuring has no recognisable influence, all plots showing similar behaviour.

This close connection between early summer rainfall and nitrogen content of grain is not confined to Woburn, it is found also at other centres, where the Institute of Brewing barley experiments were made. The explanation probably is that nitrate taken up by the plant after its first few weeks of growth tends to raise the nitrogen content of the grain rather than to produce more grain. Early summer rainfall, by washing out the late-formed or excess nitrate from the soil, prevents this rise in nitrogen content. It is often stated that rainfall in July and early August plays an important part in lowering the nitrogen content, but there is no evidence for this. It may still be true, however, that the nitrogen content is lower when July is wet because, as shown below, low temperature in July tends to reduce nitrogen content, and a wet July is often a cool one. The maturation and therefore the quality of the grain may, however, be improved by July rain.

Effect of Temperature.

Up to the middle of May (i.e. for the first 8 or 10 weeks after sowing) variations in temperature have but little effect

on the nitrogen content of the grain except a slight lowering on the plots receiving complete artificials as the temperature rises.

From mid-May on till harvest, however, temperatures above the average raise the nitrogen content. The effect depends somewhat on the manuring—thus differing from the rainfall effect; it is least pronounced on the farmyard manure plot and most on the plot receiving nitrate of soda. The most sensitive period is mid-July: at this time an excess of 5° C. above the average temperature raises the nitrogen content as follows:—

Increase in Percentage of Nitrogen.	Plot.	Manured.
0·0076	1, 7, and 4	No nitrogen, unmanured minerals only.
0·0128	3, 6	Nitrate of soda.
0·0083	5	Sulphate of ammonia.
0·0059	11b	Farmyard manure.

The effect cannot be sharply disentangled from that of rain because wet days in summer are often cooler than dry ones.

Forecasting of Nitrogen Content.

The nitrogen content is so closely connected with early summer rainfall and July temperature that a "forecast" of the nitrogen content of the grain over the whole period can be constructed from a knowledge of these two quantities. Table 86 shows the "Forecast" for Plot 6: no fewer than 75 per cent of the results came within 0·15 of the values actually found. Of course it does not follow that the same equation will continue to fit the points in the future, and if there had been 100 years instead of 40 the equation might have been different. Nevertheless, the fact that it holds for 40 years opens up some interesting possibilities, for, as Bishop has shown, a forecast of the nitrogen content also enables a forecast to be made of the general chemical composition of the grain and the quantity of malt extract it can be made to yield after malting.[1]

[1] See E. J. Russell and L. R. Bishop, "Investigations on Barley," *Journal of the Institute of Brewing*, 1933, vol. 39, pp. 287 and seq.

TABLE 86.—NITROGEN CONTENT OF BARLEY GRAIN, PLOT 6, AS FOUND BY ANALYSIS AND CALCULATED FROM REGRESSIONS ON THE WEATHER VARIATES.

Year.	Per Cent of Dry Grain. Found by Analysis.	Calculated from Regression on May and June Rainfall and July Temperature. At End of July.
1885	1·73	1·77
86	—	1·72
87	1·81	1·70
88	1·81	1·78
89	1·67	1·53
1890	1·85	1·83
91	1·93	1·60 —
92	1·66	1·93 +
93	—	2·01
94	1·73	1·78
95	2·38	2·27
96	—	2·16
97	1·90	2·00
98	1·56	1·66
99	1·87	2·09 +
1900	1·99	2·10
01	2·36	2·12 —
02	1·63	1·68
03	1·60	1·39 —
04	1·83	2·06 +
05	2·10	1·99
06	1·72	1·83
07	1·52	1·47
08	1·64	1·86 +
09	1·68	1·72
1910	1·49	1·64
11	2·51	2·30 —
12	1·78	1·91
13	1·89	1·81
14	2·00	2·02
15	2·00	1·86
16	1·68	1·75
17	1·73	1·81
18	1·53	1·86 +
19	1·84	1·83
1920	1·59	1·66
21	2·44	2·34
22	1·65	1·80
23	2·07	2·13
24	1·44	1·37
25	2·29	2·03 —
26	1·96	1·77 —

Number of times calculated differs from actual nitrogen per cent. by more than ·15 = 11, i.e. 25 per cent. These occasions are marked + when the forecast is too high and — when it is too low.

Effect of Cultural Operations.

Date of Sowing.—February is in general the best month for sowing barley, and although later sowings have not much affected the yield, no doubt because the time was well chosen, they have been accompanied by a tendency to higher nitrogen content. Each week's delay after the end of February has meant an addition of something like 0·05 per cent to the nitrogen content of the grain. Delays in sowing also increased the nitrogen content of the grain in the Institute of Brewing experiments on barley grown in rotation.

Date of Applying the Nitrogenous Manure.—No specific experiments were made at Woburn, but the continuous putting off of the date of application of the nitrogenous fertilizer is associated with no continuous change in nitrogen content. It is possible, as with the deterioration, that the tendency for a rise was there, but that it was masked by the substitution of Plumage Archer for the older varieties from 1922 onwards.

Effect of Fallowing.—One of the most remarkable results obtained at Woburn is the extraordinary effect of fallowing on the yield and nitrogen content of the succeeding barley

TABLE 87.—YIELD AND NITROGEN CONTENT OF BARLEY GROWN AFTER FALLOWING.

Previous Manuring.	Yield, cwt. per Acre.			Nitrogen Content.		
	No Manure.	Farmyard Manure.	Minerals only.	No Manure.	Farmyard Manure.	Minerals only.
Plot	1 and 7	11b	4	1 and 7	11b	4
10-year average before fallow (1917-1926)	3·61	12·26	4·67	1·82	1·93	1·85
After fallow: First year, 1929	9·36	16·87	9·93	1·33	1·33	1·28
Second year, 1930	5·61	9·50	6·32	1·43	1·39	1·38

grain. All the plots were fallowed in 1927 and 1928; they were then sown with barley but no manure was given. The yields rose very considerably and the nitrogen content fell. The data are given in Table 87.

No manure was given on any plot in 1929 and 1930.

Nitrogen Content of Wheat Grain.

The wheat grain contained as at Rothamsted about 0·2 to 0·3 per cent more nitrogen than the barley; the averages are given in Table 88.

TABLE 88.—AVERAGE NITROGEN PERCENTAGE IN WHEAT GROWN UNDER VARIOUS CONDITIONS.

	Plot.	Woburn. 1885–1906.	Woburn. 1907–1926.	Rothamsted, Broadbalk.	Ordinary English. Average of Recent Values.	Canadian.[1] Prairie Provinces.	Canadian.[1] Maritime Provinces.
No manure . .	1	2·02	1·87	1·85	2·0	2·9	2·4
Minerals only .	4	2·09	1·89	1·88			
Nitrogen only .	3	2·20	1·95	2·07			
Minerals + nitrogen 41 lb. . .	6	2·16	1·91	2·02			
Farmyard manure	11b	2·11	1·97	2·24			

The nitrogen content of English-grown wheat varies over a rather wide range (1·8 to 2·6 per cent), but the average of recent available analyses is 2·0 per cent [2] while barley usually contains about 1·4 to 1·8. The Woburn wheat was thus during its first period richer in nitrogen than the Broadbalk wheat, just as the barley had been; this accords with the general result that sandy soils yield on the average grain of higher nitrogen content than the heavier loams. During

[1] F. T. Shutt, *Trans. Roy. Soc. Canada*, 1935, 29, p. 1.

[2] For wheat it is usual, especially in Canada, to state the percentage in terms of protein = N × 5·7. The protein content thus derived for English wheats is 11·4 per cent, but as it is usual to calculate on a basis of 15 per cent moisture this reduces to 9·7 per cent. For the above Canadian averages the values are 16·5 and 13·5 respectively.

the second period the wheat has almost the same nitrogen content at the two centres except on the farmyard manure plots. The Woburn wheat is about as rich in nitrogen as the average for England, though it is below that of Canada even in the Maritime Provinces where soft wheats are grown.

In general millers prefer a wheat of high nitrogen content, and they esteem the prairie wheats above the others. Nitrogen content, however, is far from being the sole criterion, and the Rothamsted wheats have not done well in milling and baking tests. No tests, however, have been made of Woburn wheats.

The causes of fluctuation in nitrogen content seem to be much the same for wheat as for barley, but they act differently on the two crops. For both crops the nitrogen content of the grain is raised by nitrate of soda and lowered by minerals applied in addition. Years of high nitrogen content for barley tend also to be years of high nitrogen content for wheat, but the figures are not closely related. As for barley, the nitrogen content tends to be lower in years of high yield and *vice versa*. For both crops too, rainfall acts in the same direction, though not to the same extent. Additional rain tends to raise the nitrogen content if it falls in March, but to lower the nitrogen content if it falls during the actual growing season (May-June). But there is a difference between the two crops towards harvest time. Additional rainfall in early August, which has no recognisable effect on the nitrogen content of barley, distinctly raises that of wheat. Higher July temperatures tend to raise the nitrogen content of barley but not of wheat.

So far as the growing period is concerned the result (as for barley) agrees with that obtained elsewhere ; in an investigation of Canadian wheats continuing over 28 years, Shutt [1] found that high nitrogen content was associated with dry soil conditions and low nitrogen content with

[1] F. T. Shutt, "The Nitrogen Content of Wheat as Affected by Seasonal Conditions," *Trans. Roy. Soc. Canada*, 1935, vol. 29, p. 1.

moister conditions. But we know of no other instance where higher rainfall in early August raised the nitrogen content.

No explanation can be offered for the remarkable drop of about 0·2 per cent in the nitrogen content of the wheat after 1906. There is no such fall for barley (p. 185).

The Weight of the Grain.

Two methods are in use for estimating the weight of the grain.

On the farm it was for long customary to take the weight of a measured bushel and the average results were published in the statistics of the Ministry of Agriculture. The bushel measure, a cylindrical wooden vessel, was placed on the floor of the barn and grain was poured into it out of a sack till it was well heaped up. The side of the vessel was struck with a wooden stick with a smooth straight side like a thick ruler. The stick was then run over the top of the measure, its smooth side being on the rim, so as to wipe off the excess of grain. The measure was then emptied and the grain weighed.

The figures have an element of artificiality in that no attempt was made to reduce the grain to its closest packing by lifting or shaking the vessel; nevertheless, a competent farm worker obtained remarkably uniform results.

This method was used both for wheat and for barley; it is now generally given up, and the sacks of grain from the threshing machine are weighed and not measured. For barley grain a second method is used by maltsters. Several samples each of 1000 corns are weighed, and the mean is called the thousand corn weight. This still remains in use.

The two methods naturally do not agree since they represent fundamentally different things, and moreover, the values are not related in the same way to manurial or seasonal conditions. We shall therefore consider them separately.

Bushel Weight.

The bushel weight of the grain at Woburn is below what is usually obtained on British farms ; the values are :—

	Woburn. Limits.	Woburn. Average.	Usual English.[1]
Barley	51·1—53·1	51·8	54
Wheat	56·4—59·9	58·7	62

Manuring had a perceptible though not great effect. For barley the average values on the plots without nitrogen were below the general mean, and those on the plots receiving sulphate of ammonia were above it. Complete artificials gave higher bushel weights than incomplete, and sulphate of ammonia gave higher weights than nitrate of soda. For wheat the addition of minerals raised the bushel weight in presence of nitrogenous manure, and sulphate of ammonia gave higher weights than nitrate of soda. But the differences are in all cases small (Table 89).

TABLE 89.—AVERAGE BUSHEL WEIGHTS IN LB. OF WHEAT AND BARLEY 1877–1926.

	Barley.	Wheat.
Unmanured (Plots 1 and 7) . .	51·1	58·8
Minerals only (Plot 4) . . .	51·5	58·9

Nitrate of Soda Set.	Barley.	Wheat.	Sulphate of Ammonia Set.	Barley.	Wheat.
Nitrate of soda only (Plot 3a) . .	51·1	56·4	Sulphate of ammonia only (2a) . .	52·1	58·2
Nitrate of soda + minerals (6) . . .	51·9	58·4	Sulphate of ammonia + minerals (5a) .	52·7	59·6
(Double nitrogen), (9) .	51·6	58·3	(Double nitrogen), (8)	52·4	59·8

	Barley.	Wheat.
Nitrate of soda omitted (9)	52·3	59·4

The bushel weights do not vary with the yield ; there is nothing to show, as is sometimes assumed, that in years of low yields the bushel weight is also low. Also the bushel weights were not related to the quantity of tail corn ; increased proportions of tail corn did not mean lower bushel

[1] Taken from Min. Agric. Statistics. Average of values for 16 years, 1906–21.

weight, as is often stated. Further, the values show no steady deterioration as the years pass on. For the last 20 years they are certainly lower than for the first 30, but the change came rapidly at the time of changing the manuring; within each of the periods there is no sign of a fall.

No definite relations were traced between weather conditions and bushel weight, but the fluctuations are too small to justify any detailed examination. The changes in bushel weight bore no relation to the fluctuations in nitrogen content of the grain. The only factor showing any resemblance in its fluctuations to bushel weight was the ratio of grain to total produce.

Thousand Corn Weight of Barley.

The thousand corn weight of barley at Woburn has usually been rather less than is usual for good malting samples; it has ranged from 28·7 to 49·1 grams with an average value of 37·2 grams, while for good malting sample it is usually about 38 to 40 grams.

Manuring has had no recognisable effect. In any particular year the values are all practically alike regardless of the treatment.

Season, however, has clearly had a marked effect as the values vary considerably from year to year, but curiously enough none of the meteorological factors at the time of grain formation or ripening has had any recognisable influence; no connection could be traced with rainfall, hours of sunshine, or temperature in May, June, July or August. The only connections that could be discovered were in months that seemed too remote to produce any explainable effect. Thus, rainfall in January, February, and March depressed the 1000 corn weight, the February effect being the most pronounced and accounting for 19 per cent of the annual variance. Even rainfall between September and November seemed to have some effect. Temperatures above the

average in March and April tend to increase the 1000 corn weight ; some 17 per cent of the annual variance is thus accounted for. But in no month did sunshine have any recognisable effect ; this was quite contrary to the usual statement that June sun fills out the grain.

Also there was no connection between 1000 corn weight and either the nitrogen content of the grain or the ratio of grain to straw.

CHAPTER XVIII.

THE FATE OF THE NITROGEN SUPPLIED IN THE MANURES: UPTAKE OF NITROGEN BY THE PLANT FROM THE SOIL.

SAMPLES of the barley grain had been preserved from the more important plots since 1882 and their nitrogen content has been determined. No samples of straw had been kept, but it is known that most of the nitrogen in the plant migrates to the grain, and a number of analyses at Rothamsted give as an average final partition 70 per cent in the grain and 30 per cent in the straw.

Adopting these figures for Woburn it is possible to estimate the amount of nitrogen taken up by the crop, and Dr. Walkley's analyses of the soil enable one to form an estimate of the fate of the nitrogen supplied in the various manures.

Plots Without Added Nitrogen.

Assuming the grain to contain 70 per cent of the total nitrogen assimilated, the barley crops grown on the plots without manure, and with potash and phosphate only, have taken up the following quantities of nitrogen in lb. per acre per annum during the 45 years 1882–1926 :—

	1882–1886.	1887–1891.	1892–1896.	1897–1901.	1902–1906.	1907–1911.	1912–1916.	1917–1921.	1922–1926.	Total lb. per Acre.
No manure	29	26	23	17	18	11	15	13	7	800
Minerals only .	26	29	29	22	21	13	21	17	12	950

The nitrogen uptake falls off from each period to the next, excepting only during 1909–12 when a less prolific variety, Goldthorpe, was grown, and brought down the yields considerably. The fall, however, is not smooth, it is more pronounced during some periods than during others.

Assuming nitrogen uptake was of the same order for the first 5 years, 1877–81, as for the period 1882–6, the total amounts of nitrogen obtained by the plants on the two plots over the 50 years are :—

	lb. per Acre.
Unmanured	950
Minerals only	1100

Presumably the minerals stimulated root growth and so allowed the plants to draw more completely on the soil nitrogen.

Not all of this, however, has come from the soil ; about 5 lb. per annum, 250 lb. in all, is supplied in the seed and brought down in the rain, leaving as the supply from the soil :—

	lb. per Acre.
Unmanured	700
Minerals only	850

Deducting this 5 lb. per acre, at the beginning of the period the soil was yielding up nitrogen to the crop at the rate of 20 to 25 lb. per acre, and at the end of the period at the rate of about 2 lb. per acre on the unmanured and 7 lb. per acre on the plot with minerals only. There still remained, however, in the soil :—

	Per Cent.	lb. per Acre.
No manure . . .	0·094	2820
Minerals only . . .	0·089	2670

enough for several hundred years at this rate of loss. Actually the loss is greater than this, as no account is taken of drainage, but even so there remains a large stock of nitrogen without allowing for possible bacterial fixation from the air. The nitrogen contents of the soil are given in Table 105 and

TABLE 90.—CHANGES IN NITROGEN CONTENT IN SOIL, AND QUANTITY OF NITROGEN ASSIMILATED BY THE CROPS; 50 YEARS, 1876–1927. (MEAN OF WHEAT AND BARLEY.)

	No Nitrogen Added. Plots 1, 7, and 4.
Nitrogen in soil, 1876, per cent	0·156
,, ,, 1927, ,, ,,	0·102
Nitrogen lost, per cent	0·054
,, ,, lb. per acre [1]	1620
Nitrogen found in crop [2]	770
Loss	850
Percentage recovered in crop	47
,, lost	53

	Nitrogen Added.		
	Artificials only.		Farmyard Manure.
	Nitrate of Soda only. Plot 3.	Nitrate of Soda and Minerals. Plot 6.	Plot 11b.
Nitrogen in soil, 1876, per cent	0·155	0·156	0·156
Nitrogen in soil, 1927, per cent	0·105	0·105	0·148
Nitrogen lost, per cent	·050	·051	·008
,, ,, lb. per acre	1500	1530	240
Supplied in manure	2050	1640	4800
Total	3550	3170	5040
Found in crop [2]	1600	2050	2300
Lost	1950	1120	2740
Percentage of total found in crop	45	70	45
Lost	55	30	55

[1] Accepting Warington's value of 1370 tons = 3 million lb. per acre for the top 9 inches of Woburn soil.

[2] After deduction of 5 lb. per annum from seed and rain; see p. 288.

the rate of loss at the various periods can be seen from Fig. 39.

Of the nitrogen lost from the soil part is recovered in the crop: on the unmanured land this amounts to some 50 per cent.

Probably the safest estimates of the recoveries under various manurial treatments are those in Table 90. These show that the crop obtained about half the nitrogen lost from the soil and supplied in the manure on the plots receiving farmyard manure, nitrate of soda only, minerals only, and no manure; but the recovery amounted to about two-thirds where complete artificials were given.

In this table no assumptions are made excepting that the samples represent the nitrogen content of the plot [1] and that the plant has 70 per cent of its nitrogen in the grain. The recoveries of nitrogen are from the systems soil + manure, and not from the added manure.

The only way of estimating the percentage of nitrogen recovered from the manure is to assume that the nitrogen relations between plant and soil are not altered by the presence of the manure, so that the contribution made by the manure can be ascertained by subtracting the contribution made by the soil on the plots without nitrogen. This has been done in Table 91.

The corresponding calculation for the Rothamsted plots gives, as the percentage of nitrogen from farmyard manure [2]:—

	Wheat (Broadbalk, Plot 2).	Barley (Hoos Plot 7–2).
Left in soil . . .	29	34
Taken up by crop . .	32	—

The figures for the percentage of nitrogen recovered by the crop from farmyard manure at Askov (Denmark) are

[1] Only one sample drawn from three holes was taken in 1876, and it has to be assumed that this represents the initial state of all the plots. There is now no means of knowing how far the assumption is justified.

[2] A. D. Hall, *Fertilisers and Manures*, 1909, p. 211.

TABLE 91.—FATE OF ADDED NITROGEN ASSUMING NO CHANGE IN THE SOIL DECOMPOSITIONS: AVERAGES FOR WHEAT AND FOR BARLEY.

	Farmyard Manure.		Artificials only. Nitrate of Soda + Minerals.	
	Lb. per Acre per Annum.	Per Cent.	Lb. per Acre per Annum.	Per Cent.
Nitrogen left in soil . .	28	29	...	...
Taken up by crop . .	31	32 [1]	26	78
Not accounted for . .	41	39	7	22
Total supplied in manure .	96	100	33	100

30 and 28 on a loam and sand respectively. This seems to suggest some general figure of about 30 per cent, and it is probably not far wrong to round off the figures roughly and put the fate of the nitrogen under these conditions as follows :—

	From Soil Without Nitrogenous Manure.	From Nitrate of Soda.	From Farmyard Manure.
In crop.	About one-half.	About two-thirds.	About one-third.
In soil.	...	...	About one-third.
Lost.	About one-half.	...	About one-third.

As the annual additions of farmyard manure continue, the quantity of nitrogen it leaves in the soil decreases so that the loss becomes greater.

Wheat Data.

Samples of wheat grain had also been preserved, and these have been analysed. It is, however, less easy to deduce values for total nitrogen uptake since a larger proportion of the total nitrogen remains in the straw and therefore the correction is larger. The average distribution of nitrogen between grain and straw as determined from a number of

[1] By a curious coincidence the corresponding figures for Broadbalk, Rothamsted, are also 32 per cent for farmyard manure and 78 per cent for nitrate of soda (A. D. Hall, *Fertilisers and Manures*, 1909, p. 211).

analyses is approximately 2 : 1 : these values have been used in preparing Table 92. In individual 5-year periods

TABLE 92.—NITROGEN LB. PER ACRE PER ANNUM, IN GRAIN AND STRAW, AVERAGE OF 5-YEAR PERIODS.

Plot.	1882–1886.	1887–1891.	1892–1896.	1897–	1902–1906.	1907–1911.	1916.			Total 1882–1926.
					Barley.					
1 and 7	29	26	23	17	18	11	15	13	8	802
4a	26	29	29	22	21	13	21	17	12	950
2a	51	58	47	13	2	...	...	...	...	
3a	57	50	51	42	36	27	21	19	18	
5a	54	57	60	17	6	...	...	...	...	
6	67	60	65	55	47	26	29	25	21	1972
9 with nitrogen	89	77	84	75	72	39	33	32	27	2638
9 no nitrogen	48	40	46	33	31	22	23	20	16	1394
11b	70	49	64	51	52	44	40	43	28	2202
					Wheat.					
1 and 7	33	27	20	19	18	19	17	17	7	883
4a	35	27	18	17	16	17	14	19	9	800
3a	54	46	36	40	32	33	24	28	16	1540
6	71	61	48	54	45	34	28	36	18	1980
11b	62	59	44	48	48	41	33	44	18	1984

there are differences between the wheat and the barley values, but for the total uptake over the 58 years these differences in no case exceed 10 per cent, and in two out of the five cases they fall below 5 per cent. It seems safe to assume, therefore, that the wheat and the barley under similar treatments have obtained approximately the same quantity of nitrogen from the soil that the deductions made for barley hold for wheat also.

The Possibility of Predicting Yields of Cereal Crops.

The development of statistical methods of studying field data opens up the hope that crop yields might be forecasted with some degree of accuracy. So much in the history of the growing plant depends on something that has happened

earlier in its life that there is always the possibility of predicting from a known occurrence what the result will be.

When the effects of rainfall on wheat yields at Rothamsted were shown by R. A. Fisher to be expressible to a considerable degree by linear regressions, it was hoped that other crops might show similarly expressible relations. This, however, did not happen: neither barley nor mangolds at Rothamsted, nor wheat nor barley at Woburn, have shown significant relations with rainfall or with other meteorological conditions when examined by this method. The effect of rainfall is more complex in all these cases than on the Broadbalk wheat, and it can be expressed only when the cubic and quadratic terms are taken into account. The problem continues under investigation, because of the large part that weather conditions play in determining crop yields, but it may well happen that our methods of measuring them do not afford an adequate measure of the particular meteorological factors of chief importance in crop production.

Another possibility of prediction is presented by the close relation between total produce and yield of grain discussed on page 219. The life-history of the plant proceeds in two stages: first the production of plant material, carbohydrates, proteins, etc., then the translocation of part of these substances to the grain. These stages overlap, but the formation of plant material is practically complete some time before the grain is ripe for cutting. From a good estimate of the total produce it should be feasible to deduce a good estimate of the yield of grain that would be obtained later on at harvest time. This problem is now being studied in detail at Rothamsted.

CHAPTER XIX.

THE MANURIAL VALUE OF THE NITROGEN IN THE FEEDING-STUFFS.

It was certainly a disappointment to all those concerned in the Woburn experiments that this important problem, for the study of which Woburn was set up, should have remained unsolved. In spite of the wide difference in composition between the maize-meal and the cotton cake fed to the animals, and in spite of the greater amount of nitrogen expected and probably present in the excretions of the cake-fed animals, there was no corresponding difference in manurial effect. If the result were generally true it would mean that numbers of farmers on entering a new holding have been called upon to pay compensation to the outgoing tenant for "unexhausted manurial values" that will never benefit them. The results lose considerable value from the frequent changes in plan, and criticism can be directed against the details, but they show clearly that the assumption of high and persistent manurial values of foods fed on the farm is not well founded. The experiments have served the very useful purpose of demonstrating the need for finding a new basis of assessment of compensation. This has been further emphasised in recent years by the grazing experiment carried out under the ægis of the Royal Agricultural Society in Leicestershire.[1] Here the feeding of cake to bullocks on pasture led to no visible improvement, and yet an incoming tenant would have been called upon to pay a considerable amount for it.

[1] *J. Roy. Agr. Soc.*, 1929, p. 176.

The original plan included the use of farmyard manure and of folding. Although the main objection of the rotation experiments was not achieved, some useful information was obtained about both of them which, while not capable of critical examination, is worth recording.

The Effect of Farmyard Manure.

One objection to the plan of the experiments is that the quantities of farmyard manure were too small to bear any relation to conditions in practice. The dressings at the outset were only about 4–5 tons per acre every 4 years. While this increased the yield of the roots to which it was applied the amounts were too small to reveal any differences, even if they had existed, between dung made from animals receiving cake, and that from animals receiving the less nitrogenous corn. The effect of farmyard manure on the root crop (but not on the others) can be estimated from the 1904–11 series: during the 3 years in which roots were grown (1908–10) the results were :—

YIELD OF ROOTS, TONS PER ACRE.

	No Manure. (Average Plots 1–4.)	Farmyard Manure. (Average Plots 5–8.)
Roots, tons per acre .	10·21	13·72

DETAILS OF FARMYARD MANURE PLOTS.

Cotton Cake.	Maize meal.	No Cake or Meal.	
Plot 5.	Plot 6.	Plot 7.	Plot 8.
13·36	13·20	14·07	14·18

A better basis of comparison would have been the nitrogen balance sheets of the various treatments. This is not now possible as the necessary analyses were not made at the time, but estimates based on such values as can be obtained, and on average compositions where no data exist, enable us to form some idea of the quantities involved.

It is rather remarkable that so small a dressing of farmyard manure as 4–5 tons per acre should have given an additional $3\frac{1}{2}$ tons of swedes per acre. Normally these would

contain about 25 lb.[1] of nitrogen per acre, while the manure had supplied about 60 lb., so that the crop recovered some 40 per cent of the nitrogen supplied which is somewhat greater than the recovery on the permanent plots (p. 291). The design of the experiment does not enable one to see whether there were any residual effects. At Rothamsted the recovery of nitrogen by the crop during 4 years was about 30 per cent from the manure made with cake, and a little less from the manure made without it.[2]

All farming experience, however, is against the use of such small dressings, and indeed in the Permanent Wheat and Barley series 3–4 tons per acre of farmyard manure had no effect till after four dressings in successive years had been given. In a later experiment at Rothamsted, where cake-fed dung was compared with dung made without cake or corn, but where the dressings were larger (16 tons per acre), the cake-fed dung proved considerably the better, but only in the first year: in the second and subsequent years the two lots of dung behaved alike (Table 93).

TABLE 93.—COMPARISON OF CAKE-FED DUNG AND ORDINARY DUNG, ROTHAMSTED 9 YEARS, 1904–12. TOTAL PRODUCE PER ACRE OF UNMANURED CROP = 100.

	1st Crop, Year of Application.	2nd Crop.	3rd Crop.	4th Crop.
Cake-fed dung .	173	138	120	113
No cake given .	144	135	126	117

The Woburn result resembles that obtained at Rothamsted in the second year after application.

These results suggest that a distinction must be drawn between the effects of dung that persist for several years,

[1] Warington's analyses of a number of samples show an average content of 7 lb. nitrogen per ton.

[2] *Rothamsted Guide*, 1913, p. 47: Little Hoos results.

which at Rothamsted are much the same whether the cake is fed or not, and the temporary benefit conferred by cake, which at Rothamsted lasted one year, and at Woburn apparently not as long as that.

Effect of Sheep Folding.

The root crops were not usually carried away from the land, but were fed to sheep which were confined on the plot so that they might tread the soil, thus compacting it as well as enriching it with their droppings. The method has long been regarded as one of the surest for maintaining or increasing productiveness of light soils at a high level, but no figures have so far as we know been obtained to show the effects produced on the crops.

The arrangement adopted during the years 1886–97 permits a comparison of plots which were folded with those that were not but had their roots carried off. No manure was given. Unfortunately, the comparison can be made only for three out of the four crops of the rotation because the fourth, the root crop, was in one case mangolds and in the other swedes. For the three comparable crops, however, the results are given in Table 94:—

TABLE 94.—EFFECT OF FOLDING OF SWEDES ON THE YIELD OF THE FOLLOWING CROPS.

	Unfolded. No Manure. Plots 5 to 8.	Folded. No Manure. Plots 1 and 2.
Barley, total produce, cwt.	27·7	38·6
,, grain ,,	12·7	17·5
Clover-hay ,,	37·7	43·8
Wheat, total produce ,,	41·5	44·6
,, grain ,,	16·8	17·8

The folding has thus added nearly 5 cwt. grain and 6 cwt. straw per acre to the barley and 6 cwt. per acre to the clover sown in it. Even the wheat following the clover is benefited to the extent of 1 cwt. grain and 2 cwt. straw per acre, though whether this is directly attributable to the folding, or a result of the increased clover crop, is not clear. The

yield of barley on the folded plot is somewhat lower than on the permanent plots receiving complete artificial fertilizers with 41 lb. nitrogen as nitrate of soda (19·2 cwt. for the period 1887–96), while that on the unfolded plot is much above the continuous plot receiving minerals (10·0 for the period 1887–96). By interpolation one arrives at a figure of 22 lb. nitrogen per acre, or about $1\frac{1}{4}$ cwt. nitrate of soda, as the equivalent of folding with roots and a little corn. A somewhat higher figure, 30 lb. nitrogen, or $1\frac{3}{4}$ cwt. nitrate of soda, is obtained from the results for two plots in the set which show that an additional 18 lb. of nitrogen as nitrate of soda added 3 cwt. grain per acre to the yield. We shall probably not be far out in estimating the effect of the folding in this experiment as roughly equivalent to a dressing of $1\frac{1}{2}$ cwt. nitrate of soda, or 25 lb. nitrogen per acre. This value is of the same order as was obtained in the Norfolk experiments.[1]

The folding had been on a low level, about 3 to 5 tons of roots per acre only being fed, and assuming as before the average nitrogen content of 7 lb. per ton, and adding the nitrogen of the concentrated food (p. 9), we obtain an approximate value of about 45 lb. nitrogen per acre supplied, of which about 25 lb. appears in the crop; a recovery of about 55 per cent, which is higher than that for the farmyard manure.

[1] *Norfolk Chamber of Agric. Rpt. of Expts.*, 1890, p. 33. The yields of barley were in bushels per acre:—

	Roots Carted.		Roots Fed.
No manure.	$1\frac{1}{2}$ cwt. guano + $3\frac{1}{2}$ cwt. salt.	$1\frac{1}{2}$ cwt. nitrate of soda + $3\frac{1}{2}$ cwt. salt.	$3\frac{1}{2}$ cwt. salt.
31·2	49·1	44·6	46·3

Later results at Sprowston are in *Husbandry*, vol. 5, p. 20, 1935. After carted swedes at Sprowston 1 cwt. sulphate of ammonia added 7 bushels per acre (average 1923–7). After folded swedes it added nothing (1928–30). Presumably, therefore, the folding has been at least as effective as 1 cwt. sulphate of ammonia. Half the roots were carted off.

The Failure of the Additional Nitrogen to Manifest Itself.

The estimates given above of nitrogen recovered from the farmyard manure and the folding do not seem particularly low, and they suggest nothing abnormal about the experimental conditions. As compared with the effects of the nitrogen in nitrate of soda on the permanent plots put at 100 they give 55 as the value for the nitrogen in farmyard manure and 80 as the value in folded foodstuffs. In rotation experiments made in cylinders at New Jersey the corresponding value of nitrogen in farmyard manure was 53; and values of the same order have been obtained elsewhere. One must not, of course, carry any of these comparisons too far. The important point is that they do not suggest any abnormality about the effects of farmyard manure at Woburn. The unexpected result was the ineffectiveness of the enriching nitrogen supplied by the cake.

An effect had been produced on the heavier soil at Rothamsted where much larger dressings were given, but even here this enriching nitrogen had suffered heavy loss, only 14 lb. being recovered in the crops out of 50 supplied, a recovery of 28 per cent. On this basis a recovery of only 5 lb. would have been expected at Woburn over most of the period of the experiments, a quantity which is too small to be certain about. A difference of this order was in fact obtained, though it is not statistically significant (Table 95).

TABLE 95.—YIELDS ON THE VARIOUS FOLDED PLOTS.

	Cotton Cake. Plot 1.	Maize-meal. Plot 2.	No Cake or Meal but Equivalent Quantities of Fertilizer. Plots 3 and 4.	
Barley, total produce, cwt.	40·5	36·6	44·4	37·7
,, grain ,,	18·2	16·7	19·9	16·7
Clover-hay ,,	42·9	44·7	48·3	46·0
Wheat, total produce, ,,	45·3	43·8	44·3	43·7
,, grain ,,	18·1	17·5	17·8	17·5

There is, however, no indication of increased crop in the first period when the manuring was on the higher scale, and when a 25 per cent recovery should have led to substantial gains.

In the original scheme two plots were included to see how nitrate of soda compared with the animal excretions as fertilizer, and these showed the usual differences in yields corresponding with their nitrate supply: the additional 26 lb. per acre of nitrogen as nitrate of soda supplied to Plot 3 gave a further 57 cwt. of roots as compared with Plot 4, while the additional 19·2 lb. nitrogen supplied to the barley gave an extra 26·8 cwt. grain and 7·1 cwt. total produce per acre. Calculated as returns per cwt. of nitrate of soda these increments are quite normal:—

INCREASE PER ACRE, PER CWT. NITRATE OF SODA.
PLOTS 3 AND 4.

	Average 1877–85.	Average of many results elsewhere.
Roots, cwt.	38	30
Barley, bushels . . .	5·6	6
Wheat after clover, grain, bu. .	Nil	A not uncommon resu

It appears, therefore, that there was nothing about the conditions and no special reason why a difference in nitrogen content of the farmyard manure or animal excretions should fail to exert its full effect.

The failure of the additional nitrogen from the excretions to produce any effect on crop growth while nitrate of soda was having its normal effect can only mean that the nitrogen was either lost or rendered unavailable.[1] Loss by leaching

[1] The dates when folding commenced, and when barley was afterwards sown were:—

	Folding Began.	Barley Sown.		Folding Began.	Barley Sown.
1889–1890	Nov. 27	April 2	1905–06	Nov. 30	April 5
1891–1892	Nov. 23	March 31	1906–07	Dec. 14	April 2
1892–1893	Nov. 18	March 25	1907–08	Jan. 25	April 12
1893–1894	Dec. 4	March 26	1908–09	Feb. 4	April 14
1894–1895	Nov. 28	March 26	1909–10	Jan. 19	March 23
1895–1896	Nov. 23	March 30			

from the folded land is quite possible in view of the fact that the folding occurs during the winter months when percolation is rather high. Loss by evaporation of ammonia from the soil is also possible as is a disengagement of gaseous nitrogen, though actions of this type are not definitely established. Microbiological fixation of ammonia and nitrate in presence of organic matter and its conversion into complex and unavailable nitrogenous substance is known to take place.

As the experiment was carried out the nitrate of soda would not have been affected by these causes of loss to anything like the same extent as the animal excretions, and in consequence it was in a better position to exert its normal effect.

This serious loss of activity of nitrogen in presence of organic matter is not confined to the rotation experiment, it occurs in the green-manuring experiments where green tares and green mustard were both ploughed in as preparation for wheat, and yet failed to supply anything like the expected quantity of nitrogen to the crop.

CHAPTER XX.

THE UNCERTAINTY OF GREEN MANURES.

ANOTHER of the wholly unexpected results at Woburn was the failure of green manures to benefit the wheat crop. Both mustard and tares were tried; they yielded a fair amount of organic matter, and the tares contained on the average 40 lb. per acre more nitrogen than the mustard,

TABLE 96.—MEAN YIELDS, CWT. PER ACRE OF MUSTARD AND OF TARES GROWN TO BE PLOUGHED IN AS GREEN MANURE. WOBURN.

	Stackyard.		Lansome.		Both Fields.	
	Mustard.	Tares.	Mustard.	Tares.	Mustard.	Tares.
Green matter						
1st crop .	29·7[1]	81·8[1]	54·1	80·7	43·6	81·2
2nd crop .	10·0[2]	5·2[2]	23·8	59·5	17·0	32·4
Total .	39·7	87·0	77·9	140·2	60·6	113·6
Dry matter .						
1st crop .	6·0	14·2	12·9	19·2	9·4	16·7
2nd crop .	2·9	4·6	3·8	8·4	3·3	6·1
Total .	8·9	18·8	16·7	27·6	12·7	22·8
Nitrogen, lb. per acre .						
1st crop .	12	54	25	74	19	64
2nd crop .	10	22	11	64	10	39
Total .	22	76	36	138	29	103

Stackyard.	Lansome.
1st crop—1930–3.	1st crop—1902, 1905, 1930, 1932.
2nd crop—1930–2.	2nd crop—1930, 1932.

[1] 3 years only, 1931–3. [2] 2 years only, 1931–2.

presumably fixed from the air. The results are shown in Table 96.

Yet the green manure was almost ineffective; deterioration of yields was about as marked as on the unmanured land. The result is in curious contrast with those obtained in other experiments, in which both the residues of clover and of lupins certainly benefited the succeeding crop. Two comparisons can be made between clover and mustard:—

1. During the period 1905–10 mustard was substituted for clover as the green crop in the rotation experiments, and the wheat yields fell at once and considerably. They rose again, however, when clover was restored. The total produce in cwt. per acre was:—

After Clover.		After Mustard.		After Clover.	
1886–89	36·7	1906–07	40·1	1912–31	30·4
1890–93	40·2	1908–10	22·0		
1894–97	38·8	1911–12	16·2		

2. During five separate years wheat was grown after clover in the rotation experiments and after tares and mustard in the adjacent green-manuring experiment, the treatments otherwise being similar. The yield in all cases was higher after clover than after either of the others: they were, in cwt. per acre of total produce:—

	After Clover.	After Tares.	After Mustard.
1920 . . .	35·4	18·0	18·8
1924 . . .	24·3	12·5	14·2
1925 . . .	38·0	12·4	8·4
1928 . . .	27·0	13·2	14·1
1929 . . .	22·6	13·1	11·7
Mean . . .	27·2	13·8	13·5

As no analysis of produce were made, and no samples were kept, it is not possible to state even approximately the amount of nitrogen contained in the additional wheat crops and presumably derived from the clover. On the basis of Warington's average nitrogen content of the wheat crop—48 lb. nitrogen per 44 cwt. total produce one can estimate the

total amount in the crop at about 40 lb. per acre. This figure has some confirmation from the fact that during the 25 years of the middle period 1886 to 1910 the wheat following the clover yielded about as well as on Plot 6 of the continuous series, which also contained about 40 lb. nitrogen per acre. Plot 6 had received complete artificials, including nitrate of soda supplying 41 lb. nitrogen per acre. Of course this does not represent the whole of the nitrogen fixed by the clover, but only the fraction taken by the wheat. There is no way of estimating the balance.

The experiments with lupins are not strictly comparable with the above since the lupins were grown in spring and ploughed under in July; kale was sown immediately after. The experiment was so arranged as to test the respective values of the roots and the tops as manure; only the latter had value but it was very marked (Table 97).

TABLE 97.—YIELDS OF KALE AFTER PLOUGHING LUPIN RESIDUES INTO THE SOIL, TONS PER ACRE,[1] 1934.

Ploughed-in.	Nitrogen contained in Part Ploughed-in, lb. per Acre.	Kale, Tons per Acre
1. Nothing (lupin tops and roots removed)	0	3·53
2. Lupin roots only	11·3	3·17
3. Lupin, whole plant, roots and tops	133·6	6·68
4. Lupin, whole plant plus tops from treatment 2	256	8·47

The Rothamsted soil is much heavier than that of Woburn and would be expected to behave rather differently to green-manuring. Yet here as at Woburn autumn-sown vetches proved ineffective for the following spring-sown crops while autumn-sown rye was actually harmful to the barley and the sugar-beet (Table 98).

[1] *Rothamsted Annual Report*, 1934, p. 28.

TABLE 98.—EFFECT OF GREEN MANURES ON VARIOUS CROPS, ROTHAMSTED. MEANS OF ALL MANURIAL TREATMENTS, YIELDS PER ACRE, 1934.

	Potatoes.	Barley.		Sugar-beet.	
		Grain.	Straw.	Roots.	Tops.
	Tons.	Cwt.	Cwt.	Tons.	Tons.
No green manure .	5·91	27·2	30·0	12·62	10·63
Vetches ploughed-in .	5·54	27·2	30·1	11·86	9·10
Rye ploughed-in .	6·14	20·4	25·0	11·59	5·96

Yield of green manures, April 13: rye, 5 tons green weight, 13 cwt. dry matter; vetches, 0·6 ton green weight, 1·2 cwt. dry matter.

A full account of the field experiments on green-manures and sheep-folding has been given elsewhere by E. M. Crowther and H. H. Mann,[1] together with the results of related laboratory and pot-culture work. About two-thirds of the nitrogen in tares is converted very rapidly into nitrate, but mustard, in consequence of its lower nitrogen percentage, nitrifies much more slowly and may actually remove nitrate from the soil in the first stages of decomposition. There is also evidence that a considerable fraction of the nitrogen added may be lost from the soil as gas.

The green-manure wheat rotation allows active decomposition of crop residues and soil organic matter with loss of nitrogen both as gas and by leaching of nitrates. In addition a considerable proportion of the nitrogen fixed by tares is nitrified and lost during the winter whilst the wheat is growing too slowly to utilise it.

A number of the experiments made in different parts of the country under the Royal Agricultural Society Research Scheme also gave negative results.[2] There is evidently a considerable amount to learn about green-manuring, and it cannot be recommended generally without careful experiment to find out the conditions in which it is likely to succeed.

[1] *J. Roy. Agr. Soc.*, 1933, vol. 94, pp. 128-51.

[2] *Ibid.*, 1926, p. 296, and *Rothamsted Conference Reports*, 1927, vol. 3, p. 23.

CHAPTER XXI.

THE FEEDING EXPERIMENTS.

THE results of the feeding experiments have not been examined in detail because the figures are unsuitable for statistical study, and as at the time they were done the idea of balancing for starch equivalent had not yet been introduced, direct comparisons of feeding-stuffs are not usually possible; in consequence there is nothing to add to the account given in Chapter VIII. All the problems investigated were important at the time and some still are. The results of the experiments have passed into practice, and even the investigations themselves have sometimes been forgotten. It is, for example, rather tragic that some of the recent publications on silage should make no reference to the admirable pioneering work done at Woburn and at Rothamsted in the years 1884–7, the first in this country and still among the best.

After the first trials silage was made that proved as good as roots and hay, and when compared on the basis of equal areas of grassland, it was immaterial whether the grass was made into hay or into silage; the feeding results were the same. Whichever process was the cheaper was therefore the better.

Several of the experiments, e.g. those on heavy as against light cake-feeding, and on economy in root-feeding, deal with the problem that still continues to occupy agriculturists: is it more profitable to fatten animals rapidly by heavy feeding or to let them grow more slowly? On general grounds one would say at once that the quicker they are

fattened the better, since they need less food for maintenance. But practical farmers often maintain that it is not so; that better results are obtained by the slower than by the more rapid methods. Actually the experimental evidence is not very clear; the heavy cake-feeding in the 1892 experiment gave the larger daily live-weight gains and the greater financial profit, but in the 1896 experiment on economy in root-feeding there was very little financial difference between the results of rapid and of slower fattening.

Some of the grain-feeding results are interesting. Wheat was fed to sheep (1885–7 experiments) apparently without trouble and even with success. Many farmers would consider this procedure risky, and indeed at Rothamsted we have had trouble with it. The failure of barley as a supplement to linseed cake in the sheep-feeding experiments of 1891–2 is interesting, but even more so is the important result that oatmeal and separated milk proved better and more economical as food for calves than anything else tested. The perennial question of mangolds as sheep feed was also studied, and it was shown that, used carefully, mangolds were as good as swedes. Many of the experiments have the merit of recording the amount of water consumed by the animals; data of this kind are not easily accessible elsewhere.

The data for 7 years are given in Table 99 as an illustration of the quantity of water consumed. There is considerable variation as between one experiment and another, much more than can be explained by variations in size of animal or in conditions of feeding. In point of fact, these conditions were fairly uniform: the animals were fed in boxes during the winter, but of course the winter temperatures varied. There were also, and perhaps for this reason of temperature variation, considerable differences in water consumption in different periods of the experiments: this is well illustrated by the experiments of 1890:—

Period.	Average Water Consumption, lb. per Head per Day. Lot 1. Heavy Cake.	Lot 2. Light Cake.	Lot 3. No Cake.
1st 41 days .	54·0	48·3	31·4
2nd 41 ,, .	59·5	53·5	33·9
3rd 29 ,, [1] .	67·4	61·6	52·7

TABLE 99.—WATER CONSUMED PER HEAD PER DAY IN THE WOBURN BULLOCK FEEDING EXPERIMENTS.

J.R.A.S.E. Reference.	Days' Feeding.	Average Initial Live-weight, cwt.	Mean Water Consumed, lb. per Head per Day.	Nature of Housing.	Nature of Feeding.
1886, p. 237	22	9·1	53·0	Feeding boxes	Turnips, straw-chaff, cake and meal
1888, p. 482	112	10·0	43·1	,, ,,	Swedes, hay, straw, cake and meal
1888, p. 482	112	10·1	35·9	,, ,,	Swedes, hay, straw, home-grown corn
1888, p. 484	112	10·0	28·5	Open yard	Swedes, hay, straw, home-grown corn
1890, p. 404	110	10·0	59·7	4 in boxes, 2 in open yard	Roots, hay, full cake
1890, p. 404	110	10·0	55·8	4 in boxes, 2 in open yard	Roots, hay, half cake
1890, p. 404	110	9·9	38·0	Covered shed	Roots and hay only, no cake
1891, p. 589	145	13·1	36·3	Feeding boxes	Roots, chaff, cake, and meal, decorticated cotton cake
1891, p. 589	145	12·3	27·6	,, ,,	Roots, chaff, cake, and meal, undecorticated cotton cake
1891, p. 591	127	10·5	50·8	4 in boxes, 4 in open yard	Roots, hay, chaff, barley, decorticated cotton cake
1891, p. 591	127	10·5	49·9	4 in boxes, 5 in shed	Roots, hay, chaff, barley, undecorticated cotton cake
1892, p. 726	107	10·5	38·0	Feeding boxes	Roots, clover, hay, home-grown foods
1892, p. 726	107	10·5	37·2	,, ,,	Roots, clover, hay, cake
1895, p. 164	61	9·6	53·4	,, ,,	Barley, straw, cake, corn, linseed oil
1895, p. 164	61	9·7	27·1	,, ,,	Barley, straw, cake, corn, roots
1895, p. 166	45	10·8	33·2	,, ,,	Barley, straw, cake, corn, roots
1896, p. 45	94	9·5	32·8	4 in boxes, 2 in covered shed	Swedes, mangolds, hay, straw-chaff, cake

[1] Mangolds substituted for swedes in last period (*J. Roy. Agr. Soc.*, 1890, pp. 401–3).

TABLE 99.—WATER CONSUMED PER HEAD PER DAY IN THE WOBURN BULLOCK-FEEDING EXPERIMENTS.—*Continued.*

J.R.A.S.E. Reference.	Days' Feeding.	Average Initial Live-weight, cwt.	Mean Water Consumed, lb. per Head per Day.	Nature of Housing.	Nature of Feeding.
1896, p. 45	94	9·5	23·2	4 in boxes, 2 in covered shed	Swedes, mangolds, hay, straw-chaff, cake, and corn
1896, p. 566	112	9·7	47·7	4 in boxes, 2 in covered shed, 2 in open yard	Light roots, hay, straw-chaff, cake, corn
1896, p. 566	112	9·7	38·1	4 in boxes, 2 in covered shed, 2 in open yard	Heavy roots, hay, straw-chaff, cake, corn
1901, p. 304	123	9·8	44	Yard with shelter	Roots, hay and straw, cake and meals, spice
1901, p. 304	123	9·8	47	Yard with shelter	Roots, hay and straw, cake and meals, molasses
1902, p. 335	106	10·2	40	Boxes	Roots, hay and straw-chaff, home-grown corn
1902, p. 335	91	11·4	49	Yard	Roots, hay and straw-chaff, home-grown corn
1902, p. 335	98	10·2	42	Boxes	Roots, hay and straw-chaff, cake
1902, p. 335	84	11·4	54	Yard	Roots, hay and straw-chaff, cake
1913, p. 410	132		7·5	Boxes	Roots, straw-chaff, corn
1913, p. 410	132		14	,,	Roots, straw-chaff, corn and hay
1917, p. 246	95		25	,,	Roots, hay, straw, meal
1917, p. 246	95		35	,,	Roots, hay, straw, meal + extra hay
1917, p. 246	95		36	,,	Roots, hay, straw, meal + extra cake
1917, p. 246	95		41	,,	Roots, hay, straw, meal + malt culms

A few measurements on sheep showed that they consumed 1½ to 2 lb. water

Sheep average live-weight, 117 lb.

Winter feeding, 108 days. Water consumed 16·25 cwt., i.e. 1·7 lb. per head per day.

They were fed with hay, straw-chaff, treacle, linseed cake.

[1] *J. Roy. Agr. Soc.*, 1902, p. 344.

Within a given experiment and over the same period where the conditions are kept as closely alike as possible certain results seem to emerge. The years of the experiments are given in brackets and the details are recorded in the appropriate volumes of the *Journal Royal Agricultural Society* :—

1. The addition of extra hay or cake to a ration resulted in greater water consumption (1890, 1913, 1917).

2. Animals consuming cake drank more water than those fed on corn (1888, 1896, 1902 ; in 1892, the amounts of water were equal).

3. Animals consuming a dry oily food, straw-chaff plus linseed oil required much more water than those receiving roots (1895).

4. As the root ration is increased, the consumption of water declined (1896).

5. A very bulky dry food, such as malt culms, required much water (1917).

Losses in Making Farmyard Manure.

The erection of special bullock-feeding boxes in 1877 by the Duke of Bedford allowed of the possibility of studying the losses in making and in storing farmyard manure. The foods fed to the animals were weighed and analysed, the animals were weighed, and the nitrogen in their live-weight increase calculated from Lawes and Gilbert's earlier analyses of animal carcasses. So the amounts of nitrogen expected in the excretions was obtained and added to the quantity present in the litter. This showed what should be present in the resulting manure. Actually there was always less, and work done elsewhere showed that the loss was due partly to volatilisation of ammonia, partly to microbial action.

The dung had been very carefully made, and protected against mechanical loss by weather or rain-water. Yet the loss of nitrogen, as shown in Table 100, amounted to about

15 per cent. This figure agrees closely with other estimates of the losses in making farmyard manure under careful conditions, and it probably represents the minimum loss which no practical farmer could avoid. Other determinations have been as follows :—

Maercker and Schneidewind (Germany), 1896–7 .	13
T. B. Wood (Cambridge)	14
E. J. Russell and J. G. Goodwin (Wye) .	15
Muntz and Girard (France)	27–36

After the manure had been made it was drawn out from the boxes and made into a heap in the open, where it remained from early winter to spring. The heap was made better than usual ; it was well covered with earth and suffered no loss of liquid. Nevertheless, analysis showed considerable loss of nitrogen, which even in these favourable conditions amounted to a further 15 per cent, making a total loss of over 30 per cent (Table 100). In ordinary farming conditions

ABLE 100.—Loss of Nitrogen in Making and Storing Farmyard Manure Produced by Consumption of Foods by Fattening Bullocks, 1899, 1900, and 1901 (Woburn).

	For Continuous Wheat Experiments.						For Continuous Barley Experiments.					
	Manure as Removed from Boxes.			Manure as Applied (after Storing) to Land.			Manure as Removed from Boxes.			Manure as Applied (after Storing) to Land.		
	1899.	1900.	1901.	1899.	1900.	1901.	1899.	1901.	1902.	1899.	1900.	1901.
	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
Total nitrogen estimated to be in manure.[1] . .	34·2	32·4	29·9	34·2	32·4	29·9	34·2	32·4	29·9	34·2	32·4	29·9
Total nitrogen actually found in manure . .	29·9	26·5	25·0	21·3	20·9	19·8	32·1	26·7	24·7	22·5	22·8	20·4
Loss of nitrogen .	4·4	5·9	4·9	12·9	11·5	10·0	2·2	5·7	5·2	11·7	9·6	9·5
Percentage loss of total nitrogen .	12·9	18·3	16·4	37·7	35·5	33·6	6·3	17·7	17·4	34·2	29·7	31·8

[1] Calculated from foods consumed after deducting live-weight increase (Lawes nd Gilbert).

it is almost certainly more, and the usual estimate of 50 per cent loss of the nitrogen added in feeding-stuffs is probably not excessive.

Influence of Foods on the Bulk of the Manure.

So far as the writer knows the Woburn experiments are the only ones yet made in this country to discover the influence of foods on the bulk of the manure. The investigation was undertaken because in the North of England the practice had developed of assessing compensation on the basis of the bulk of manure left in the yards. The tenant was penalised if he sold hay from the farm during the last years of his tenancy, but compensated on the basis of "bulk of manure" if he brought it in; 1 ton of hay was assumed to yield approximately 5 cubic yards of manure.

Direct experiment showed that both hay and malt culms increased the bulk of the manure, but while the feeding of 1 ton of hay added nearly 1½ tons to the manure (the animals having consumed much more water than those without hay), it added only about 2½ cubic yards to its bulk; the northern estimate was thus too high.

The increase in bulk is apparently attributable to the large amount of fibre in the hay and the malt culms. Palm-nut cake gave no increase (Table 101).

TABLE 101.—EXTRA BULK OF MANURE RESULTING FROM THE CONSUMPTION OF FEEDING-STUFFS, 1916–17.

	Standard Diet.	Hay, Additional Half-Ton.	Palm-Nut Cake, Additional Half-Ton.	Malt Culms, Additional Half-Ton.
Weight of manure (cwt.)	74·4	86·8	75·8	96·1
Nitrogen content of manure (per cent).	0·467	0·495	0·750	0·665
Bulk of manure (cubic feet)	149	181	153	189
Increase in bulk from one ton additional feed (cubic yds.)	—	2·4	0·3	2·9

It was further observed [1] that the feeding of hay improved the making of the manure, the straw being better broken down, and also observed that the hay had enriched the manure in nitrogen. The actual record was :—

Manure Made.	Moisture per Cent.	Nitrogen per Cent.
Without hay . . .	75·82	0·480
With hay . . .	74·21	0·615

No connection between these observations was recorded and no notice was taken of them at the time. Eight years afterwards H. B. Hutchinson and E. H. Richards quite independently made similar observations but recognised the connection, and so started their very fruitful investigations on the making of artificial farmyard manure which are continuing to yield valuable results.

[1] *J. Roy. Agr. Soc.*, 1913, p. 411.

PART IV.

By E. M. Crowther, D.Sc., F.I.C.

CHAPTER XXII.

THE SOILS OF THE WOBURN PLOTS.

The soils of Stackyard and Lansome Fields and of most of the rest of the Woburn farm are light sandy loams of considerable depths derived from drift over Lower Greensand. Although the surface soils are fairly uniform in texture, the subsoils are much less regular, the predominant material being a reddish-brown or yellow sand with irregular patches of somewhat heavier material with lighter colour, or of flint and sandstone gravel cemented by iron oxide. There are many stones of varied origins. Flints, Bunter pebbles, quartzite, fragments of ironstone and sandstone illustrate the variety of drift materials, whilst flint flakes, and bits of Roman tile, Elizabethan wine bottles, churchwarden pipes, coal, charcoal, and brick testify to the long influence of human activity. In occasional summers the cereal and other crops in Stackyard Field show two or three long diagonal lines about a foot wide in which the crops are notably taller and greener, presumably through the residual effect of earlier hedges, ditches or footpaths.

A mineralogical analysis (Table 102), by J. Hendrick and G. Newlands,[1] showed that the main components of the sands and silts were rounded quartz and oxides of iron.

[1] *J. Agr. Sci.*, 1923, vol. 13, p. 1.

TABLE 102.—MINERALOGICAL ANALYSIS OF STACKYARD FIELD SOIL.

	Fine Gravel.	Coarse Sand.	Fine Sand
Orthoclase group	nil	nil	6·2
Quartz group	56·7	97·3	90·4
Ferrosilicate group (mainly oxides of iron)	43·0	2·7	3·4

Chief minerals noted in fine sand, silt and fine silt in approximat order of abundance: Quartz, haematite, limonite, biotite, tourmalin epidote, magnetite, hornblende, garnet, zircon.

The Lower Greensand contains appreciable amounts o glauconite—a potash-iron-aluminosilicate— particles of whic are occasionally found in the soil. This mineral probabl provides some available potash and accounts for the com paratively poor responses to potash on this light soil.

To the south of the farm the soils are much heavier the drift contains much Oxford Clay material and the wate table generally stands within a few feet of the surface.

Grassland Soil Profile.

The general nature of the soil may be illustrated by the following description and analyses (Table 103) from a profile excavated in a grass field about twenty yards to the north of the hedge separating it from the Permanent Wheat plots in Stackyard Field and opposite the middle of Plot 7.

The mechanical composition is uniform down to 24 inches, below which there is a sudden fall in the silt content and an increase in the coarse sand and stones. The clay fraction shows a high ratio of silica to alumina and a high iron content. The increase of the iron/aluminium ratio with depth and the cementation of the fourth horizon, afford evidence of pod-solisation, most of which probably took place long ago under different conditions of vegetation and climate.

The rapid decrease of organic matter with depth and the poverty of the deep subsoil are shown by the following analyses (Table 104) for composite samples taken in 1876

TABLE 103.—DESCRIPTION OF PROFILE.

Horizon.	Depth in Inches.	
1	0–7½	Dark brown fine sandy loam.
2	7½–16	Dark yellowish-brown fine sandy loam.
3	16–24	Yellow to grey-brown fine sandy loam, drying out to clods.
4	24–42	Reddish-yellow, hard, impervious layer, with black iron concretions. At 36 inches a hard layer of rounded flints and angular sandstone fragments indurated with iron oxide.
5	42–60	Loose reddish-brown sand sharply separated from the layer above.

Mechanical Analysis (oven-dry fractions as percentages of air-dry soil).

Horizon.	Depth in Inches.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Moisture.	Loss on Solution.	Carbonates.
1	0–7½	39·0	30·5	11·0	10·8	2·9	1·0	0·0
2	7½–16	40·6	32·3	12·3	10·5	1·8	0·7	0·0
3	16–24	32·5	36·8	16·4	11·5	1·7	0·4	0·0
4	24–42	53·8	31·6	3·5	9·3	1·4	0·2	0·0
5	42 +	55·3	30·2	1·8	11·0	1·7	0·1	0·0

Chemical Analysis of Clay Fractions (percentages of oven-dry clay—N. H. Parberry's analyses).

Horizon.	Depth in Inches.	Loss on ign.	SiO_2.	Al_2O_3.	Fe_2O_3.	TiO_2.	$\frac{SiO_2}{Al_2O_3}$.	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$.	$\frac{Fe_2O_3}{Al_2O_3}$.
1	0–7½	27·7	38·7	15·7	10·9	0·60	4·18	2·90	0·44
2	7½–16	19·8	40·2	18·5	16·4	0·75	3·69	2·36	0·56
3	16–24	13·5	43·8	19·9	18·1	0·74	3·73	2·36	0·58
4	24–42	10·4	44·1	19·7	20·4	0·68	3·80	2·29	0·66
5	42 +	9·6	42·7	20·1	20·3	0·60	3·51	2·19	0·66

from five places in Stackyard Field. The results are also of interest as giving a comparison of two early series of analyses by an old and abandoned method with the current Kjeldahl method.

TABLE 104.—NITROGEN IN DEPTH SAMPLES OF STACKYARD FIELD. SOIL TAKEN IN 1876. PERCENTAGE OF AIR-DRY SOIL.

Depth in Inches.	By Soda Lime Method in 1878. (J. H. Gilbert.)	By Soda Lime Method in 1891. (J. H. Gilbert.)	By Kjeldahl Method in 1932. (A. Walkley.)
0–9	0·146	0·144	0·150
9–18	0·068	0·064	0·068
18–27	0·045	0·043	0·043
27–36	0·025	0·023	0·025
36–45	0·017	0·016	0·017
45–54	0·013	0·008	

Soil Samples from Experimental Plots.

The soils of each plot of the permanent barley and wheat plots were sampled in 1888, 1927, and 1932, and a few plots were also sampled in 1898. Before the plots were marked out in November, 1876, sets of samples were taken in six successive 9-inch layers at five places in Stackyard Field; No. 1 in the gap between the permanent wheat and barley plots and Nos. 2–5 in the middle of each of the four rotation plots. These samples and those of 1888 and 1898 were taken with the Lawes and Gilbert steel box of 6 × 6 × 9 inches capacity. Each was a composite sample from three holes per plot.

In 1927 the surface samples were cut to 9 inches by a spade and the subsoils taken from 9 to 18 inches by small steel cylinders. Four or five holes were taken on each plot. In 1932 the samples were taken in two independent series, each of 10 holes, by a small semi-cylindrical sampling tool: for most of the analyses recorded here the two sets were compounded.

The rotation plots were sampled in 1885 and 1899 by the box method and in 1932 by the soil sampling tool. On Lansome Field samples were taken frequently and analysed at the time for nitrogen, but many of these samples were not retained and sometimes the depth of sampling was uncertain.

Throughout the discussion and tables the surface soil

samples refer to a depth of 9 inches, unless otherwise stated, and the analyses are expressed on the air-dry soil. The moisture content was generally between 1·0 and 1·5 per cent. When necessary, the analytical data may be converted into weights per acre by using the conversion factors: 1 acre of soil to 9 inches weighs 1370 tons, and from 9 to 18 inches, 1420 tons. Although the series of soil samples is incomplete and none are available for the critical period around 1906, it is possible to follow some of the changes associated with the progressive decline in fertility and some of the secondary effects of the manures.

The detailed analytical data for the permanent wheat and barley plots are given in Tables 115 and 116 at the end of this chapter and are preceded by brief descriptions of the methods of analysis employed. Most of the data were obtained in the Chemistry Department at Rothamsted by post-graduate workers and members of the staff, whose names are given with the data for which they were responsible.

An illustration may be given here of the possibility of serious error in estimating the organic matter contents of soils from their carbon contents, or in attaching much significance to carbon-nitrogen ratios for the total soil. Although in most Woburn soil samples the ratio of carbon to nitrogen (C/N) is about 10, it reaches 12·7 in Plot 7 and 14·0 in the adjoining Plot 8a in the 1927 wheat samples. Throughout the experiment the two unmanured wheat plots (1 and 7) had closely similar nitrogen contents, but Plot 7 had nearly as much carbon as Plot 11b with farmyard manure. The excess carbon in most of the wheat plots (especially on Plots 7 and 8 in the corner near the N.W. gate) and in a few of the barley plots was found to be due to the presence of a considerable quantity of coal and occasionally of charcoal as well. After these had been identified in the laboratory samples, quite large pieces were subsequently picked up on these plots. The sand fraction of Plot 8a (wheat) contained about 13 per cent of its carbon in a form resistant to oxida-

tion by sodium hypobromite, as compared with only 2 per cent for Plot 11b (barley) which had a carbon-nitrogen ratio of 10. By assuming that the soil organic matter on wheat Plot 8a had the usual C/N ratio of 10, it was estimated that 30 per cent of the total carbon was present in the elementary form.

It is interesting to notice that in 1924 some of the long-continued manuring and liming plots in Pennsylvania were also found [1] to contain considerable amounts of elementary carbon derived from a charcoal burner's furnace used some 70 years before the experiments began in 1868. Before the charcoal was discovered, erroneous conclusions had been drawn and widely disseminated on the relative effects of lime and limestone on the loss of organic matter.

All experiments with unreplicated plots, and especially those with systematic arrangements, are subject to irregularities of unknown magnitude. Conclusions from the Woburn soil analyses can be drawn with confidence only when a number of similarly treated plots show similar effects or when the trends over a series of repeated samplings are clear. In the following discussion the results of all relevant plots and samplings are averaged whenever possible.

The Initial State of the Soil.

It is important to remember that the soil was in a high state of fertility when the experiments were commenced. In his report [2] on the first 20 years of the experiments J. A. Voelcker mentions that Sir John Lawes caused an enquiry to be made into the earlier history of the field, which showed that it had been pasture in the thirties or forties of last century, i.e. some 40 years before the experiments commenced. Some of the unexpectedly high yields were ascribed to residues from the grass. In an earlier discussion R. Vallentine [3]

[1] J. W. White and F. J. Holben, *Soil Sci.*, 1924, vol. 18, 201.
[2] *J. Roy. Agr. Soc.*, 1897, pp. 270, 631. [3] *Ibid.*, 1888, p. 116.

recalled the very high farming always practised on the Ducal estates and said :—

"I remember nearly fifty years ago (i.e. about 1840) that the land was heavily dunged with rich fattening cattle manure for swedes and mangolds. The crops were heavier about that time than they have been of late. It was the system then to consume one half the root crop on the land by sheep. The sheep were liberally fed with oil-cake, corn, and hay or clover-chaff. The first crop of the course had a heavy dunging. The second crop, barley, was too rank, and fell down long before harvest. To consume a quantity of the produce on the land, and to supplement this by cake, corn, etc., tended, as a matter of course, to produce heavy crops. This was the system pursued for a long time on the Woburn Park Farm. . . . I remember the heavy crops of barley perfectly well, as I was a working pupil at the time, and the laid, twisted corn was a difficult task for me to cut with the point of the scythe."

He makes no reference to the days when the field was under grass.

In a recent letter to Dr. H. H. Mann, Mr. C. P. Elliot, the Duke's agent, stated that the earliest record of the field occurred in an old terrier dated 1822, at which time the field was pasture. There was no further record until 1866, but for the ten years following this the field was cropped in a rotation of fallow, barley, clover, wheat. It is certain then that the field was broken up some time between 1822 and 1866 and probably in the thirties or forties—the period of great expansion in arable farming in England.

Taking into consideration the above facts, it is difficult to agree with the view that the high state of fertility of this field in the early days of the experiments was due to the fact that it had been under grass fifty years previously, particularly when one considers the great rapidity with which this soil loses organic matter under arable conditions. There seems little doubt that the fertility of the soil in 1876 was due

to the heavy dressings of organic manures applied during the previous 50-year period of exceptionally high farming.

Soil Organic Matter under Continuous Wheat and Barley.

The summary in Table 105 of the changes in the nitrogen contents of the soils of the permanent wheat and barley plots shows that on all plots without farmyard manure, the nitrogen contents fell from about 0·16 per cent to 0·10 per cent, i.e. about one-third of the soil nitrogen was lost from the surface soil in 50 years.

TABLE 105.—NITROGEN AS PERCENTAGE OF AIR-DRY SURFACE SOIL IN THE PERMANENT WHEAT AND BARLEY PLOTS (A. WALKLEY'S DATA).

Initial value in 1876 0·156 per cent.

Manuring.		Farmyard Manure.	Nitrate of Soda.	Sulphate of Ammonia.	No Nitrogen.	Mineral Manures.	No Mineral Manures.
Plots.		11b.	3, 6, 9.	2, 5, 8.	1, 4, 7.	4, 5, 6.	1, 2, 3.
Date.	Crop.						
1888	Barley	0·160	0·142	0·139	0·131	0·132	0·143
1888	Wheat	0·171	0·130	0·136	0·134	0·129	0·128
1898	Barley	—	0·120	0·121	0·123	0·112	0·127
1898	Wheat	—	—	0·126	0·129	0·124	0·132
1927	Barley	0·151	0·107	0·100	0·092	0·090	0·100
1927	Wheat	0·145	0·102	0·103	0·112	0·107	0·101
1932	Barley	0·123	0·100	0·095	0·091	0·097	0·097
1932	Wheat	0·124	0·099	0·099	0·108	0·103	0·100

The two plots with farmyard manure had about the same nitrogen contents in 1927 as in 1876. In other words, the addition of dung containing about 105 lb. of nitrogen per acre for 30 years and about 82 lb. of nitrogen per acre for 20 years just sufficed to balance the losses of nitrogen from the soil. There was some evidence in the 1888 samples that the nitrogen content of these dunged plots rose slightly with the higher rate of application in the early years.

In the 5 years 1927–32, when the plots were fallowed twice and cropped three times without manure, there was

clear evidence of a marked loss of nitrogen from the farmyard manure plots, one half of the excess of nitrogen in the farmyard plots over the other plots or about 16 per cent of the total being lost in 5 years. During this 5-year period the loss of nitrogen from Plots 1 to 9 (i.e. those without organic manures from 1876 to 1927) was comparatively slight (about 6 per cent of the total). The losses thus tended to follow the actual organic matter contents.

The effects of inorganic fertilizers on the losses of organic matter from the soil were very small. On the barley plots the nitrogen content of the soil tended to increase in the order: no-nitrogen, sulphate of ammonia, nitrate of soda, but on the wheat the no-nitrogen plots retained most nitrogen. These differences probably depend on positional rather than manurial effects, for the no-nitrogen wheat plots are close to a hedge with a row of trees, from which they receive every year substantial amounts of leaves and twigs. The soil near these trees is sometimes notably darker in colour than other parts of the field.

After 50 years the excess of nitrogen in the farmyard manure plots over that in the average of the three no-nitrogen plots was 0·059 per cent for barley and 0·033 per cent for wheat. These amounts correspond to about 1800 lb. and 1010 lb. of nitrogen per acre respectively, and are equivalent to recoveries in the soil of 38 per cent and 21 per cent of the total amount of nitrogen (about 4800 lb. per acre) estimated to have been applied as farmyard manure in the course of the 50 years. No great significance should, however, be attached to these figures, in view of serious discrepancy which developed between the wheat and barley strips of no-nitrogen plots. Similar calculations for the accumulation in the soil of nitrogen from the inorganic manures would give positive values for the barley plots of 28 per cent for nitrate of soda and 15 per cent for sulphate of ammonia, but for the wheat plots negative ones of 18 per cent and 17 per cent respectively. Such discrepancies merely reflect the

irregularities already noted between the wheat and barley strips of no-nitrogen plots. It seems unsafe to reject the wheat ones, and probably the safest course would be to take the average for the two crops and conclude that within the wide limits of error the accumulation of soil nitrogen from inorganic manures and the associated crop residues was very small. By comparing the two farmyard manure plots with the average of Plots 1 to 9 for both crops, the estimated retention of farmyard manure nitrogen is about 30 per cent.

After grouping the various subdivisions of the sulphate of ammonia plots into series without lime (8 plots), with light liming (6 plots), and with heavy liming (6 plots), the mean nitrogen percentage of the soils are 0·102, 0·103 and 0·099 per cent respectively in 1927, and 0·099, 0·097 and 0·098 per cent in 1932. The differences between these values are so small as to be negligible and there is thus no evidence that liming appreciably affected the organic matter contents of these soils. The extra crop residues produced through liming must have been balanced by larger amounts of weeds and by less rapid oxidation of organic matter on the very acid plots.

Soil Organic Matter under Rotations.

The greater part of Stackyard Field was originally devoted to testing the residual manurial value of feeding-stuffs and consisted of four large blocks of plots, one for each stage of the four-course rotation. For the first 8 years the plots received dung twice in each 4 years, but subsequently, with the object of exhausting the land, the dung was discontinued and corn or cake was fed to sheep once in each rotation.

In Table 106 the average nitrogen contents of the corn and cake plots (Nos. 1 and 2) on three of these blocks are compared with those of the continuous cereal plots for four occasions over 56 years. It will be noticed that the considerable initial differences between the blocks were main-

TABLE 106.—NITROGEN PERCENTAGE OF SOILS IN ROTATION AND IN CONTINUOUS CROPPING, STACKYARD FIELD (A. WALKLEY'S DATA).

Mean of Rotation Plots 1 and 2.					Permanent Wheat and Barley Plots.	
Year.	Rotation I.	Rotation III. (Series C.)	Rotation IV. (Series D.)	Mean of I., III., IV.	Year.	Plots 1–9.
1876	0·157	0·142	0·166	0·155	1876	0·156
1886	0·154	0·138	0·158	0·150	1888	0·135
1899	0·134	0·122	0·151	0·136	1898	0·124
—	—	—	—	—	1927	0·103
1932	(0·097 *)	0·103	0·115	0·106	1932	0·099

* Green-manure experiment since 1911.

tained, Rotation IV. having high and Rotation III. having low nitrogen contents consistently.

In the first 10 years the loss of nitrogen from the rotation plots was small and only about one-fifth of that on the continuous cereal plots without organic manures. In 23 years the rotation plots lost as much nitrogen as the continuous cereal plots lost in 12 years, but by 1932 the nitrogen contents on the rotation plots had fallen almost to the same level as the cereal plots at the interruption of the experiment in 1927. Blocks III. and IV. which were cropped in rotation throughout 56 years, lost about 30 per cent of their initial nitrogen contents. Block I. was changed to a two-course—wheat and summer green manure—rotation in 1911, and after 21 years appeared to have lost nitrogen more rapidly than the two blocks which remained in four-course rotation.

The large positional effects in the rotation plots were maintained in spite of the changes in the area and position of the plots receiving corn and cake residues, which were in strips of one-quarter, one-eighth, and one-half of each block at the time of the sampling in 1886, 1899, and 1932 respectively. Similar positional effects are to be expected in the comparisons of the plots receiving corn and cake, set out in Table 107. The differences in carbon and nitrogen contents are small and little significance can be attached to

them. In seven of the eight pairs of comparisons the cake plots gave slightly higher carbon contents than the corn plots ; the differences in nitrogen were smaller and less consistent.

TABLE 107.—STACKYARD FIELD ROTATION PLOTS. CARBON AND NITROGEN AS PERCENTAGES OF AIR-DRY SURFACE SOILS (A. WALKLEY'S DATA).

	Rotation I.		Rotation III.		Rotation IV.		Mean.	
	Corn.	Cake.	Corn.	Cake.	Corn.	Cake.	Corn.	Cake.
Carbon.								
1885–1886	1·44	1·48	1·42	1·30	1·55	1·77	1·47	1·52
1899–1900	1·29	1·33	1·20	1·21	1·52	1·62	1·34	1·39
1932	(Green manures)		0·98	1·01	1·07	1·22	1·02	1·12
Nitrogen.								
1885–1886	0·151	0·156	0·142	0·134	0·156	0·160	0·150	0·150
1899–1900	0·134	0·133	0·122	0·123	0·149	0·153	0·135	0·136
1932	—	—	0·102	0·104	0·110	0·120	0·106	0·112
C/N Ratio.								
1885–1886	9·5	9·5	10·0	9·7	10·0	11·1	9·8	10·1
1899–1900	9·6	10·0	9·8	9·8	10·2	10·6	9·9	10·1
1932	—	—	9·6	9·7	9·7	10·2	9·6	10·0

Soil Organic Matter and Green Manures.

The carbon and nitrogen percentages in the soils of the green-manure experiments in Stackyard Field (Table 108) and Lansome Field (Table 109) are generally similar to those in the continuous cereal plots. In both fields there is evidence of progressive loss of organic matter in spite of the folding-off or ploughing-in of green crops every second year. In both fields also, the tares gave rather higher carbon and nitrogen contents than the mustard.

In 1928–9 T. J. Mirchandani [1] made periodic determinations of the ammonia and nitrate contents in the tares and mustard plots in Stackyard and Lansome Fields and showed

[1] *J. Agr. Sci.*, vol. 21, 1931, p. 458 ; E. M. Crowther and T. J. Mirchandani, *ibid.*, 493.

TABLE 108.—STACKYARD GREEN-MANURE PLOTS. CARBON AND NITROGEN AS PERCENTAGES OF AIR-DRY SURFACE SOILS (A. WALKLEY'S DATA).

Date.	U = Unlimed, L = Limed.	Tares.	Wheat after Tares.	Mustard.	Wheat after Mustard.
Carbon per cent.					
1921	U	0·97	—	0·90	—
Nov. 1929	U	1·04	1·05	1·03	0·90
Sept. 1932	U	1·00	0·93	0·88	0·88
Sept. 1932	L	1·01	0·90	0·87	0·82
Nitrogen per cent.					
Nov. 1920	U	0·114	—	0·098	—
1921	U	0·111	—	0·104	—
Nov. 1929	U	0·104	0·108	0·104	0·092
Sept. 1932	U	0·107	0·097	0·091	0·093
Sept. 1932	L	0·105	0·104	0·092	0·088
C/N Ratio.					
1921	U	8·6	—	9·5	—
Nov. 1929	U	10·0	9·7	9·9	9·8
Sept. 1932	U	9·3	9·6	9·7	9·5
Sept. 1932	L	9·6	9·5	9·5	9·3

TABLE 109.—LANSOME GREEN-MANURE PLOTS. CARBON AND NITROGEN AS PERCENTAGES OF AIR-DRY SURFACE SOILS (A. WALKLEY'S DATA).

Date.	Depth in Inches.	Fallow.	New Tares.	New Mustard.	Old Tares.	Old Mustard.
Carbon per cent.						
1921	9 ?	—	—	—	0·88	0·90
Aug. 1932	9	1·02	1·13	1·06	0·90	0·77
Oct. 1932	9	1·02	1·13	1·06	0·86	0·78
Nitrogen per cent.						
1904	6 ?	—	—	—	0·140	0·111
Nov. 1909	6 ?	—	—	—	0·118	0·097
Feb. 1914	?	—	—	—	0·086	0·086
May 1915	?	—	—	—	0·099	0·097
Sept. 1915	9	—	—	—	0·085	0·082
Nov. 1920	?	—	—	—	0·114	0·098
1921	9 ?	—	—	—	0·088	0·086
Aug. 1932	9	0·099	0·110	0·100	0·086	0·073
Oct. 1932	9	0·096	0·107	0·096	0·083	0·073
C/N Ratio.						
1921	9 ?	—	—	—	10·0	10·4
Aug. 1932	9	10·3	10·3	10·6	10·4	10·4
Oct. 1932	9	10·6	10·6	11·0	10·3	10·5

that in autumn the tares residues yielded the greater quantity of nitrate, which was, however, lost before the wheat could utilise it in the following spring. The field results and the pot culture and chemical work on green manuring at Woburn have been fully discussed by E. M. Crowther and H. H. Mann.[1]

Exchangeable Bases.

The Woburn soil had little or no calcium carbonate at the commencement of the experiments and no provision was made in the original design of Sir John Lawes and Dr. A. Voelcker for meeting the extra loss of lime induced by the use of ammonium salts. Dr. Voelcker had shown[2] from analyses of drainage waters from Broadbalk Field in 1866-69 that ammonium salts greatly increased the loss of lime as sulphate and nitrate, and in discussing his analyses in 1881-2 Lawes, Gilbert, and Warington[3] wrote, "The action of ammonium salts in impoverishing a soil of lime and magnesia should always be borne in mind when their application to soils poor in lime is considered."

The failure on the sulphate of ammonia plots after about 20 years and the repeated subdivision of plots for liming at different times and rates provide suitable material for studying the effects of continuous cropping, manures and lime on the reaction and exchangeable base content of a light soil. The 1927 series of soil samples and some of the earlier ones were analysed by J. K. Basu,[4] and the 1932 series was analysed for exchangeable calcium by B. S. Ellis, who used an improved method.

Some discrepancies between the 1927 and the 1932 series

[1] *J. Roy. Agr. Soc.*, 1933, vol. 94, p. 128.

[2] *J. Chem. Soc.*, vol. 24, 1871, p. 276; *J. Roy. Agr. Soc.*, Second Series, vol. 10, 1874, p. 132.

[3] *Ibid.*, vol. 18, 1882, p. 22.

[4] London University Ph.D. Thesis, 1930. For fuller discussions of the results and their agricultural significance, see E. M. Crowther and J. K. Basu, *J. Agr. Sci.*, vol. 21, 1931, pp. 689–715, and E. M. Crowther, *J. Roy. Agr. Soc.*, vol. 93, 1932, pp. 199–213.

led to a repetition of the exchangeable calcium and *p*H determinations in the 1927 and earlier series. In the present discussion and tables the revised values by a uniform method are used.

Table 110 gives the exchangeable calcium and *p*H values

TABLE 110.—EXCHANGEABLE CALCIUM AND *p*H VALUES OF SURFACE SOILS OF STACKYARD PERMANENT BARLEY (B) AND WHEAT (W) PLOTS.

Initial Values in 1876: Exchangeable Ca = 7·8 mg. Equivalents per cent. *p*H = 6·1.

	Crop.	Plot.	Exchangeable Ca. Mg. Equiv. per Cent. 1888.	1898.	1927.	1932.	*p*H Value. 1888.	1898.	1927.	1932.
Sulphate of Ammonia Plots.										
No Minerals	B	2a	6·2	4·3	0·9	1·4	5·4	4·9	4·5	4·4
,, ,,	W	2a	5·6	3·4	0·8	1·1	5·2	4·6	4·4	4·7
Minerals	B	5a	5·1	3·3	1·4	1·4	5·5	5·0	4·8	4·7
,,	B	8a	5·5	4·4	2·5	2·0	5·4	5·2	4·8	4·7
,,	B	8b	6·0	4·5	1·9	2·6	5·5	5·2	4·7	5·0
,,	W	5a	4·6	3·7	1·9	2·4	5·4	5·0	4·8	5·1
,,	W	8a	5·4	—	1·0	1·0	5·3	—	4·5	4·8
,,	W	8b	6·6	—	1·5	1·6	5·6	—	4·8	4·8
No-Nitrogen Plots.										
No Minerals	B	1	6·8	6·3	3·7	4·3	5·8	5·4	5·5	5·4
,, ,,	B	7	7·0	—	3·8	4·1	6·0	—	5·4	5·6
,, ,,	W	1	6·3	6·9	4·9	4·6	5·8	5·8	5·7	5·6
,, ,,	W	7	7·7	—	4·2	4·3	5·9	—	5·6	5·5
Minerals	B	4a	5·7	4·7	5·0	3·6	6·0	5·7	6·0	5·4
,,	W	4	6·7	5·5	6·6	5·8	6·0	5·5	5·9	5·8
Nitrate of Soda Plots.										
No Minerals	B	3b	6·8	6·0	4·8	5·2	6·0	5·9	5·8	5·6
,, ,,	W	3b	7·5	—	5·2	5·1	6·2	—	5·8	5·6
Minerals	B	6	7·1	—	5·0	5·0	6·2	—	5·8	5·8
,,	B	9a	7·6	—	5·4	5·0	6·2	—	5·6	5·7
,,	B	9b	7·4	—	5·8	5·0	6·2	—	5·8	5·8
,,	W	6	6·2	—	5·2	4·8	6·0	—	6·1	5·8
,,	W	9a	7·7	—	5·1	4·3	6·3	—	6·1	5·8
,,	W	9b	7·5	—	5·3	4·6	6·3	—	6·2	5·7
Farmyard Manure	B	11b	7·4	—	5·9	5·3	6·1	—	5·8	5·8
,, ,,	W	11b	7·6	—	6·3	5·2	6·0	—	6·4	5·9

for all unlimed plots which had the same manuring from 1876 to 1926, apart from the general change in rates of dressing in 1905. The values for the four unmanured plots suggest that the single sample of 1876 was reasonably representative of the original state of the soil, for the exchangeable calcium in the unmanured plots fell fairly steadily within the errors of soil irregularity, sampling, and analysis, from an initial value of 8 mg. equivalents per cent in 1876 to 7 mg. equivalents per cent in 1888 and to about 4·4 mg. equivalents per cent in 1927 and 1932. The exchangeable calcium represented about 90 per cent of the total calcium content (0·25 per cent CaO in 1876).

During the 50 years the *p*H values on the unmanured plots fell from 6·1 to about 5·5. Part of the loss of exchangeable calcium must therefore be ascribed to a slight but steady increase in acidity or decrease in saturation with bases. More important, however, was the loss in saturation capacity through the loss of organic matter already discussed.

By 1888 all the sulphate of ammonia plots had less exchangeable calcium than the average of the unmanured plots, and each of them had a lower *p*H value than any one of the four unmanured plots. By 1898 the incomplete set of soil samples showed further loss of exchangeable calcium and drop in *p*H value on the sulphate of ammonia plots. The barley crops first began to fail on these plots about 1889–92, when the *p*H value reached about 5·3. The wheat failures came later: about 1896 on Plot 2a, and 1907 on Plot 5. In 1898 the *p*H values of these plots were 4·6 and 5·0 respectively, which agree with the order of failure and suggest that the critical point for wheat was about *p*H 4·8. It may also be noted that the barley on the rape-dust plot (10b) failed during the last decade of the experiments when the *p*H value was approaching 5·0.

Throughout the experiment the nitrate of soda and the farmyard manure plots had rather more exchangeable calcium and higher *p*H values than the no-nitrogen plots. Nitrate of

soda conserves exchangeable calcium through its "physiological alkalinity," or, in other words, through the circumstance that the plant takes up more nitric acid than soda or, alternatively, exchanges bicarbonate ions for nitrate ions. The basic residue or sodium bicarbonate is leached out and a corresponding amount of exchangeable calcium is conserved. Farmyard manure contains considerable amounts of calcium and other bases which are gradually set free by its decomposition. Rape-dust uses up lime because it supplies nitrifiable nitrogen without a corresponding amount of base.

From Table 110 it will be seen that the effects of mineral manures on exchangeable calcium and *p*H value were so slight that even the actual direction of the effect is not consistent. Comparisons of "minerals" versus "no minerals" may be made under three sets of conditions: without nitrogen, with sulphate of ammonia, and with nitrate of soda. There is some suggestion that minerals slightly reduced the exchangeable calcium in the early samples and increased it in the final ones, but the differences are small and irregular. When it is remembered that in 50 years the mineral plots received over 8 tons of superphosphate per acre, it is clear that the Woburn plots give no support whatsoever to the common but mistaken dogma that "superphosphate uses up lime and acidifies the soil."

Since the subdivisions for liming were made at irregular intervals and since some of the dressings were repeated, it is not possible to determine precisely the rate of loss of lime. In order to obtain as reliable averages as possible, the 1927 and 1932 results for the limed sulphate of ammonia plots were divided into two groups: with light liming (1 or 2 tons per acre, average 1·36 tons per acre) and with heavy liming (two dressings of 2 tons per acre). On the average the lime was applied about 20 years before the 1927 samplings. The mean values for these groups and some of the comparable unlimed plots are given in Table 111. They leave no doubt

about the long duration of the effects of liming on soil which is initially very acid. They also show that the loss of lime is relatively higher for heavy dressings than for light ones.

TABLE III.—STACKYARD PERMANENT BARLEY AND WHEAT PLOTS. EXCHANGEABLE CALCIUM AND *p*H VALUES. 1927 AND 1932.

	No Nitrogen.	Sulphate of Ammonia.			Nitrate of Soda.	Farmyard Manure.
		No Lime.	Light Liming.	Heavy Liming.		
No. of plots averaged	6	8	7	6	8	2
Barley plots . .	1, 4a, 7	2a, 5a, 8a, 8b	2aa, 5aa,	2b, 2bb, 5b, 8aa, 8bb	3b, 6, 9a, 9b	11b
Wheat plots . .	1, 4, 7	2a, 5a, 8a, 8b	2aa, 2b, 5b, 8aa, 8bb	2bb	3b, 6, 9a, 9b	11b
*p*H *values*.						
Surface 0–9″, 1927 .	5·7	4·7	5·1	5·9	5·9	6·1
Surface 0–9″, 1932 .	5·6	4·8	5·1	5·8	5·7	5·8
Subsoil 9–18″, 1927 .	6·0	5·7	5·9	6·5	6·4	6·2
Exchangeable calcium (mg. equiv. per cent.).						
Surface, 1927 . .	4·69	1·40	2·96	5·12	5·22	6·08
Surface, 1932 . .	4·47	1·66	2·90	4·84	4·89	5·23
Subsoil, 1927 . .	5·30	4·54	5·56	5·60	5·75	5·41
Exchangeable lime (tons CaO per acre).						
Surface, 1927 . .	1·80	0·57	1·14	1·97	2·01	2·33
Surface, 1932 . .	1·72	0·64	1·15	1·86	1·88	2·01
Surface + Subsoil } 1927 .	3·91	2·37	3·35	4·20	4·20	4·48

In 1927 the top 18 inches of soil retained over two-thirds of the lime given in the light dressings and about one-half of that given in the heavy dressing. For an average dressing of 1·36 tons of lime per acre about 0·98 ton was retained and 0·38 ton lost. Of the 2·64 tons of lime which represented the difference between the heavy and the light dressings, only 0·84 ton was retained and 1·80 tons were lost. The rate of loss of lime from the soil by drainage obviously depends on the degree of acidity and amount of exchangeable calcium

actually present, and it is thus impossible to give a general answer to the question " How long does a given dressing of lime last ? " From very acid soils lime is lost extremely slowly. Thus it is possible, e.g. in North Wales or Scotland, to maintain rotations of acid-resistant crops, such as oats, potatoes and certain grasses, without liming, since sufficient calcium is liberated by weathering, or brought up by deeply-rooting crops, or added in farmyard manure to balance the small losses by drainage. When, however, it is desired to change the cropping to include more sensitive crops, a heavy initial liming is essential and, in addition, relatively frequent dressings are required to hold the exchangeable calcium at its higher level and to make good the much larger annual wastage.

From 1927 to 1932 there was no loss of lime from the plots with low exchangeable calcium but appreciable losses from those plots which contained about 2 tons of exchangeable lime per acre in the surface soil.

Throughout fifty years the loss of exchangeable calcium from the subsoil on the sulphate of ammonia plots was comparatively small and the light liming sufficed to make good the loss.

Since the actual rate of loss of lime depends in part on the exchangeable calcium content of the soil and since the very acid plots carried negligible crops for many years, it is not safe to calculate the extent of the acidification due to sulphate of ammonia from the actual reduction in exchangeable calcium. It is much more satisfactory to consider the amount of lime needed to raise the exchangeable calcium of the sulphate of ammonia series to that of the nitrate of soda series. This not merely allows for the " physiological alkalinity," but brings in more plots and reduces errors from soil irregularities. It was found that a total dressing of 4 tons of lime per acre, applied in two dressings of 2 tons at intervals of 8 or 15 years, gave yields both of wheat and barley similar to those on the nitrate of soda plots. Further, all of the analytical data in Table 111

show that the heavily limed sulphate of ammonia plots had about the same *p*H values and exchangeable calcium contents as the nitrate of soda plots. We may conclude, therefore, that for infrequent liming in comparatively heavy dressings 4·0 tons of lime are required to offset the acidification due to 3·6 tons of sulphate of ammonia and to leave conditions similar to those obtained from an equivalent amount of nitrate of soda. These figures are equivalent to 5·4 parts of lime per part of nitrogen as ammonia, or 112 parts of lime per 100 parts of sulphate of ammonia. To convert 100 parts of sulphate of ammonia into calcium sulphate and nitrate requires 82 parts of lime (4 parts CaO per unit N). The higher figure found in the field experiments depends mainly on the wastage of lime necessarily involved in comparatively heavy and infrequent dressings. Attempts are sometimes made to estimate the acidifying effect of sulphate of ammonia by allowing for the physiological alkalinity of the resulting nitrate, but it should be remembered that the extent of this physiological alkalinity depends on the actual size and composition of the crops grown. It is simpler to take a nitrate as the standard and to assume that sufficient lime is added as required to keep both the crops and the soil of the same composition. In addition it is necessary to remember that in practice the physiological alkalinity of nitrates and the lime and magnesia in basic fertilizers, such as basic slag and cyanamide, are used most efficiently, since they are given frequently and in small amounts and, in addition, provide lime in the immediate vicinity of some other plant food. With sulphate of ammonia the acidification is often ignored, as at Woburn, until its effects are obvious and then lime must be given in relatively heavy dressings, which allow rapid losses.

Other Exchangeable Bases.

In the less acid Woburn soils the amounts of magnesium, potassium and sodium in the exchangeable form are small

in comparison with the amount of calcium. In the first 30 years the mineral manures supplied sulphates of potassium, magnesium, and sodium, as well as of calcium (in superphosphate). After 50 years about one-half of the added magnesium, one-twentieth of the added potassium, and none of the added sodium remained in exchangeable form. The greatest loss of exchangeable potassium was on the less acid plots, upon which relatively large crops were grown without added potash. On acidification the loss of base fell almost entirely on the calcium, and there was no evidence that either extreme acidity or liming affected the exchangeable potassium.

Table 112 gives the mean contents of exchangeable bases for plots with and without mineral manures.

TABLE 112.—EXCHANGEABLE BASES IN SURFACE SOILS, STACKYARD PERMANENT WHEAT AND BARLEY (J. K. BASU'S DATA).

Mg. equivalents per 100 g. soil.

	Plot.	Ca.	Mg.	K.	Na.
Average of 1888 and 1898 samples: Barley.					
Unmanured . .	1	6·8	0·94	0·24	0·42
Minerals only . .	4	5·3	1·14	0·48	0·42
Average of 1927 samples: Wheat and Barley.					
Without minerals .	1, 7, 2a, 2b, 2bb	3·6	0·59	0·13	0·29
With minerals . .	4a, 5a, 5b, 6	4·4	0·94	0·25	0·29

Readily Soluble Phosphoric Acid.

The readily soluble phosphoric acid in the 1927 surface soil samples was determined by two methods of extraction, (1) Truog's method of shaking 1 g. of soil with 200 c.c. of 0·002 N H_2SO_4 containing 3 g. ammonium sulphate per litre, and (2) extraction with 0·5 N acetic acid to 500 c.c., as in the determination of exchangeable bases. Both methods gave similar results, the second less acid reagent giving consistently lower ones. As is to be expected the plots without

minerals gave very low amounts of readily soluble phosphoric acid (from 1 to 3 mgs. per 100 g. soil). The highest values were for the mineral manure plots without nitrogen (19 mgs. and 23 mgs. per cent for Plot 4 barley and wheat respectively by the Truog method). The total phosphoric acid applied in 50 years was 1·32 tons per acre, equivalent to 96 mg. per 100 g. of surface soil. Thus, less than one-fifth of the added phosphoric acid remained in a form readily soluble in dilute acids. Plots 10a received 9·6 cwt. of phosphoric acid per acre from 1907–26, equivalent to 35 mgs. per 100 g. of surface soil, and the excess of readily soluble phosphoric acid over the comparable plots without superphosphate (11a) was only 3 mgs., or less than 10 per cent recovery of the added phosphoric acid. Most of the added phosphate was converted into a comparatively inert form, presumably an iron phosphate. Some recent preliminary analyses by L. A. Dean bring out very clearly the contrast between the neutral Rothamsted soil and the acid Woburn soil in the fixation of added phosphate. The soils were extracted with 0·25 N sodium hydroxide and a distinction was made between the inorganic and organic phosphorus in the extract, the organic

TABLE 113.—PHOSPHORIC ACID EXTRACTED FROM WOBURN AND ROTHAMSTED SOILS (L. A. DEAN'S DATA).

Mgs. P_2O_5 per cent.

	Plot.	Inorganic Alkali-soluble.	Inorganic Acid-soluble.	Total by Fusion.
Woburn Barley (1927).				
No manure	1	40	11	160
Minerals only	4	70	37	250
Minerals and s. amm.	5a	110	24	250
Farmyard manure	11b	65	23	240
Rothamsted Wheat.				
No manure	3	7	40	140
Minerals only	5	9	170	290
Minerals + s. amm.	8	9	130	260
Farmyard manure	2b	13	130	300

phosphate being resistant to oxidation by bromine. The alkali-treated soils were subsequently extracted with 0·5 N sulphuric acid. From Table 113 it is seen that in the Broadbalk wheat plots at Rothamsted most of the added phosphate remains in an acid-soluble form, presumably as hydroxyapatite. At Woburn the greater part of the added phosphate is recovered in the alkaline extract ; it appears to be present in the soil as an iron phosphate.

The Composition of the Clay Fraction.

A series of separations and analyses of the clay fractions [1] from the permanent barley plots (Table 114) showed, as might be expected, that the continued manuring had had but slight influence on the chemical composition of the clay fraction. The two very acid plots (2a and 5a) had more

TABLE 114.—COMPOSITION OF CLAY FRACTIONS FROM SOILS OF PERMANENT BARLEY PLOTS, 1927 SAMPLES (S. P. AIYAR'S DATA).

	Plot.	Depth in Inches.	Per Cent Loss on Ignition of Oven-Dry Fraction.	Percentage of Ignited Material.			$\frac{SiO_2}{Al_2O_3}$.	$\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$.	$\frac{Fe_2O_3}{Al_2O_3}$.
				SiO_2.	Al_2O_3	Fe_2O_3.			
Unmanured	1 and 7	0–9	10·8	46·7	21·2	26·2	3·72	2·08	0·79
		9–18	10·0	47·2	22·2	22·6	3·60	2·18	0·65
Sulphate of ammonia	2a	0–9	10·8	47·0	21·0	26·3	3·76	2·09	0·80
		9–18	10·7	47·8	21·8	26·3	3·70	2·09	0·77
Sulphate of ammonia and minerals	5a	0–9	11·1	44·5	20·4	27·5	3·69	1·98	0·86
		9–18	9·4	45·2	20·9	26·6	3·64	2·01	0·81
Nitrate of soda and minerals	6	0–9	12·6	45·4	21·8	23·2	3·52	2·10	0·68
		9–18	10·3	46·7	22·9	22·6	3·44	2·11	0·63
Farmyard manure	11b	0–9	13·4	46·4	22·1	21·2	3·54	2·19	0·61
		9–18	10·8	46·9	23·4	21·9	3·37	2·12	0·60

[1] S. P. Aiyar, University of London Ph.D. Thesis, 1934.

iron per unit aluminium than the other plots, which may perhaps be taken as a sign of incipient podzolization.

The Mechanical Analyses.

The results in Table 116 show that the soils of the permanent wheat and barley plots are fairly uniform in mechanical composition, except for some irregularities in the proportions of coarse and fine sand. Plot 4, wheat, which had abnormally high exchangeable calcium and organic matter, also had an appreciably higher clay fraction in the subsoil than any other plot. The progressive loss of organic matter from 1876 to 1932 is shown by the falling air-dry moisture contents and losses on ignition.

Methods of Analysis.

1. *Carbon and Nitrogen.*—All determinations were made by A. Walkley,[1] mostly on soil samples ground in a porcelain mortar to pass a 0·5 mm. sieve. The Bangor method [2] of digesting with sulphuric acid and collecting the sulphur dioxide in iodine was used. The conditions of heating were carefully standardised and the recovery factor determined by comparison with the Dennstedt dry combustion method. The digested residues were steam distilled and the ammonia absorbed in 0·02 N H_2SO_4. Although the Bangor method is not recommended for carbon determinations on a wide variety of soils, it is suitable for comparative work on a single type of soil, especially when both carbon and nitrogen are to be determined. The mean deviations between the pairs of independent duplicate samples taken in 1932 from the barley plots, expressed as percentages of the total

[1] For a detailed discussion of the methods for carbon and nitrogen, see A. Walkley, *J. Agr. Sci.*, vol. 25, 1935, 598–609, and University of London Ph.D. Thesis, 1933.

[2] G. W. Robinson, W. McLean, and Rice Williams, *J. Agr. Sci.*, vol. 19, 1929, 315.

contents, were 1·5 for carbon and 1·6 for nitrogen. The corresponding figures for the wheat plots were 2·3 and 1·9 respectively, the higher values being due partly to the presence of coal and charcoal and partly to a less critical control of the temperature of digestion in the analysis of the wheat soils.

2. *Exchangeable Calcium.*—All analyses in the following Tables were made by extracting 25 g. (or 12·5 g.) with 0·5 M. acetic acid to 1000 c.c. (or 500 c.c.), precipitating the calcium as oxalate at *p*H 4·0–4·3, and titrating the oxalate with permanganate. The 1932 samples were analysed by B. S. Ellis and all others by R. G. Warren and J. W. Dewis. In earlier work J. K. Basu [1] determined the enchangeable calcium in the 1927 and some of the earlier samples by extracting with hot N ammonium chloride. Except for a few plots, the two series of analyses agreed within sampling errors, but for uniformity it was considered better to use results from a single analytical method throughout the present tables and discussion.

3. *p*H *Values.*—All *p*H values were determined by Miss S. G. Heintze by the quinhydrone electrode, using the technique of the Soil Reaction Committee of the International Society of Soil Science. There was no drift in the potential with time. The values in the following Tables should replace the earlier ones by J. K. Basu, a few of whose determinations were subsequently found to contain a small systematic error.[2]

4. *Readily Soluble Phosphoric Acid.*—In the Truog method, used by L. A. Dean, 1 g. of soil was shaken with 200 c.c. 0·002 N H_2SO_4 containing 3 g. ammonium sulphate per litre. The phosphoric acid soluble in 0·5 M. acetic acid was determined by R. G. Warren and H. A. Smith in the extracts prepared for exchangeable calcium.

[1] University of London Ph.D. Thesis, 1930. E. M. Crowther and J. K. Basu, *J. Agr. Sci.*, vol. 21, 1931, 689.

[2] *p*H values by the hydrogen electrode on 1922 samples are given by E. M. Crowther, *J. Agr. Sci.*, vol. 15, 1925, 222.

5. *Mechanical Analyses.*—All analyses were made by W. C. Game by the standard International pipette method, using hydrogen peroxide pretreatment. The results are given as oven-dry fractions as percentages of the air-dry soil. The four fractions together with the air-dry moisture content and loss on solution (R_2O_3 dissolved in H_2O_2 treatment) add up to 100, within an experimental error of 1 or 2 per cent. The loss on ignition of the total soil is also given.

TABLE 115.—CHEMICAL ANALYSES OF STACKYARD BARLEY AND WHEAT SOILS AS PERCENTAGES OF AIR-DRY SOIL.

All Data for Surface Samples, 0–9 Inches.

Plot.	Carbon per Cent.	Nitrogen per Cent.	C/N.	Exchangeable Calcium, mg. Equiv. per Cent.	pH.
1876 *Samples.*					
No. 1. Between wheat and barley plots	1·49	0·156	9·5	7·8	6·1
No. 2. Rotation Block 1	1·51	0·157	9·6	8·2	6·2
No. 3. Rotation Block 2	1·47	0·154	9·5	7·7	6·1
No. 4. Rotation Block 3 (Series C)	1·32	0·142	9·4	9·3	6·6
No. 5. Rotation Block 4 (Series D)	1·59	0·166	9·6	9·9	6·4
1888 *Samples.* *Barley Plots.*					
1	1·26	0·144	8·7	6·8	5·8
2	1·34	0·143	9·4	6·2	5·4
3	1·33	0·143	9·3	6·8	6·0
4	1·19	0·122	9·7	5·7	6·0
5	1·28	0·134	9·6	5·1	5·5
6	1·34	0·141	9·5	7·1	6·2
7	1·21	0·126	9·6	7·0	6·0
8a	1·33	0·140	9·5	5·5	5·4
8b	1·35	0·142	9·5	6·0	5·5
9a	1·38	0·145	9·5	7·6	6·2
9b	1·46	0·140	10·4	7·4	6·2
10a	1·33	0·136	9·8	6·5	5·9
10b	1·39	0·140	9·9	6·7	6·0
11a	1·74	0·160	10·9	8·0	5·9
11b	1·57	0·160	9·8	7·4	6·1

TABLE 115 (*continued*).

Plot.	Carbon per Cent.	Nitrogen per Cent.	C/N.	Exchangeable Calcium, mg. Equiv. per Cent.	*p*H.
1888 *Samples. Wheat Plots.*					
1	1·18	0·126	9·2	6·3	5·8
2	1·26	0·131	9·6	5·6	5·2
3	1·25	0·126	9·9	7·5	6·2
4	1·25	0·127	9·8	6·7	6·0
5	1·28	0·130	9·8	4·6	5·4
6	1·29	0·129	10·0	6·2	6·0
7	1·70	0·150	11·3	7·7	5·9
8a	1·74	0·149	11·7	5·4	5·3
8b	1·62	0·142	11·4	6·6	5·6
9a	1·50	0·135	11·1	7·7	6·3
9b	1·51	0·136	11·1	7·5	6·3
10a	1·27	0·130	9·7	6·3	5·8
10b	1·38	0·143	9·5	6·8	6·2
11a	1·40	0·139	10·1	7·1	6·1
11b	1·69	0·171	9·9	7·6	6·0
1898 *Samples. Barley Plots.*					
1	1·19	0·135	8·9	6·3	5·4
2	1·16	0·127	9·1	4·3	4·9
3	1·15	0·120	9·6	6·0	5·9
4	1·09	0·111	9·8	4·7	5·7
5	1·03	0·112	9·2	3·3	5·0
8a	1·16	0·123	9·4	4·4	5·2
8b	1·19	0·123	9·7	4·5	5·2
1898 *Samples. Wheat Plots.*					
1	1·26	0·135	9·1	6·9	5·8
2	1·21	0·128	9·5	3·4	4·6
4	1·27	0·123	10·3	5·5	5·5
5	1·14	0·125	9·1	3·7	5·0
1916 *Samples. Barley Plots.*					
1	1·07	0·106	10·1	—	—
7	0·99	0·101	9·8	—	—
11b	1·60	0·160	10·0	—	—
1919 *Samples. Wheat Plots.*					
7	1·31	0·114	11·5	—	—
11b	1·44	0·143	10·1	—	—
1922 *Samples. Barley Plots.*					
1	0·93	0·100	9·3	—	—
11b	1·51	0·154	9·8	—	—

TABLE 115 (*continued*).

Plot.	Carbon per Cent.	Nitrogen per Cent.	C/N.	Exchangeable Calcium, mg. Equiv. per Cent.	*p*H.	P_2O_5 mgs. per Cent. Truog Method.	P_2O_5 mgs. per Cent. Acetic Acid Method.
1927 *Samples. Barley.*							
1	0·96	0·094	10·2	3·7	5·5	3	1
2a	0·92	0·098	9·4	0·9	4·5	3	2
2aa	1·02	0·106	9·6	3·7	5·1	3	—
2b	0·92	0·098	9·4	4·4	5·8	4	1
2bb	0·98	0·103	9·5	5·8	5·8	4	—
3a	1·04	0·105	9·9	5·2	5·9	3	1
3aa	1·01	0·105	9·6	6·5	6·2	3	1
3b	1·02	0·106	9·6	4·8	5·8	2	1
3bb	1·03	0·103	10·0	6·8	6·5	4	2
4a	0·88	0·089	9·9	5·0	6·0	19	12
4b	0·89	0·090	9·9	3·7	5·5	14	—
5a	1·02	0·100	10·2	1·4	4·8	11	10
5aa	0·89	0·092	9·7	3·5	5·4	11	10
5b	0·98	0·102	9·6	5·5	6·1	16	—
6	1·05	0·109	9·6	5·0	5·8	16	12
7	0·88	0·093	9·5	3·8	5·4	2	1
8a	0·96	0·098	9·8	2·5	4·8	12	10
8aa	0·98	0·097	10·1	4·6	5·9	16	10
8b	0·95	0·102	9·3	1·9	4·7	10	9
8bb	0·97	0·101	9·6	5·3	5·8	15	9
9a	1·00	0·108	9·2	5·4	5·6	15	10
9b	1·05	0·108	9·7	5·8	5·8	19	—
10a	0·98	0·101	9·7	3·9	5·4	6	4
10b	1·00	0·106	9·4	3·1	4·9	3	2
11a	1·12	0·115	9·7	4·4	5·6	4	2
11b	1·50	0·151	9·9	5·9	5·8	10	7
1927 *Samples. Wheat.*							
1	1·03	0·105	9·8	4·9	5·7	2	1
2a	0·98	0·094	10·4	0·8	4·4	3	2
2aa	0·97	0·106	9·2	2·6	4·8	2	1
2b	1·04	0·104	10·0	2·2	5·0	3	1
2bb	0·87	0·093	9·4	5·1	5·8	3	1
3a	1·04	0·098	10·6	5·5	6·1	2	3
3b	0·96	0·100	9·6	5·2	5·8	3	1
4	1·31	0·117	11·2	6·6	5·9	23	17
5a	1·12	0·103	10·9	1·9	4·8	13	11
5b	1·04	0·096	10·8	4·4	5·7	16	15
6	1·07	0·104	10·3	5·2	6·1	15	12
7	1·43	0·113	12·7	4·2	5·6	6	1
8a	1·57	0·112	14·0	1·0	4·5	17	14
8aa	1·12	0·110	11·2	2·0	4·9	17	14
8b	1·45	0·111	13·0	1·5	4·8	16	13
8bb	1·28	0·105	12·2	2·6	5·0	15	13
9a	1·11	0·102	10·9	5·1	6·1	15	11
9b	1·20	0·106	11·3	5·3	6·2	19	13
10a	0·99	0·095	10·4	4·4	5·9	6	4
10b	1·06	0·106	10·0	3·5	5·4	3	2
11a	0·99	0·101	9·9	4·2	6·0	3	3
11b	1·52	0·145	10·5	6·3	6·4	12	7

TABLE 115

Plot.	Carbon per Cent.	Nitrogen per Cent.	C/N.	Exchangeable Calcium, mg. Equiv. per Cent.	*p*H.
1932 *Samples.* *Barley.*					
1	0·93	0·095	9·8	4·3	5·4
2a	0·92	0·094	9·8	1·4	4·4
2aa	1·01	0·104	9·7	4·1	5·1
2b	0·89	0·093	9·6	4·7	5·8
2bb	0·92	0·096	9·6	5·7	5·9
3a	0·96	0·100	9·6	5·4	5·9
3aa	0·96	0·098	9·8	6·7	6·4
3b	0·99	0·103	9·6	5·2	5·6
3bb	0·90	0·094	9·6	6·0	6·3
4a	0·84	0·086	9·8	3·6	5·4
4b	0·86	0·088	9·8	4·5	5·7
5a	0·88	0·090	9·8	1·4	4·7
5aa	0·85	0·088	9·7	3·1	5·0
5b	0·90	0·094	9·6	4·9	5·9
6	0·98	0·100	9·8	5·0	5·8
7	0·86	0·090	9·4	4·1	5·6
8a	0·94	0·095	9·9	2·0	4·7
8aa	0·89	0·092	9·7	4·5	5·8
8b	0·94	0·096	9·8	2·6	5·0
8bb	0·97	0·101	9·6	4·7	5·9
9a	0·95	0·100	9·5	5·0	5·7
9b	0·97	0·102	9·5	5·0	5·8
10a	0·91	0·095	9·6	4·0	5·6
10b	0·92	0·096	9·6	2·9	5·1
11a	1·04	0·104	10·0	4·2	5·6
11b	1·23	0·123	10·0	5·3	5·8
1932 *Samples.* *Wheat.*					
1	0·97	0·106	9·1	4·6	5·6
2a	0·91	0·095	9·6	1·1	4·7
2aa	0·98	0·102	9·6	2·1	4·9
2b	0·85	0·093	9·2	3·0	5·0
2bb	0·90	0·098	9·2	4·6	5·3
3a	0·98	0·100	9·8	5·2	5·8
3b	0·90	0·094	9·6	5·1	5·6
4	1·18	0·112	10·5	5·8	5·8
5a	0·97	0·101	9·6	2·4	5·1
5b	0·96	0·100	9·6	4·0	5·6
6	0·94	0·096	9·8	4·8	5·8
7	1·22	0·107	11·4	4·3	5·5
8a	1·26	0·102	12·4	1·0	4·8
8aa	1·02	0·098	10·4	2·0	5·0
8b	1·18	0·102	11·6	1·6	4·8
8bb	1·11	0·100	11·1	2·5	5·1
9a	1·04	0·102	10·2	4·3	5·8
9b	1·12	0·105	10·7	4·6	5·7
10a	0·95	0·096	9·9	4·3	5·6
10b	0·93	0·101	9·2	3·8	5·4
11a	1·10	0·106	10·4	4·6	5·8
11b	1·22	0·124	9·8	5·2	5·9

TABLE 116.—MECHANICAL ANALYSES OF STACKYARD FIELD SOILS. OVEN-DRY FRACTIONS AS PERCENTAGES OF AIR-DRY SOIL.

Plot.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Moisture.	Loss on Solution.	Loss on Ignition.
1876 *Surface Soils.*							
Wheat and Barley .	47·5	25·6	13·0	11·7	1·4	0·7	4·4
Rotation IV. (Series D) .	51·9	23·8	8·0	12·7	1·7	0·7	4·7
1888 *Surface Soils.*							
Barley 1	55·2	22·7	8·3	10·7	1·2	0·7	3·9
Barley 7	54·8	21·2	10·5	11·5	1·3	0·6	3·5
Wheat 1	65·6	13·2	8·3	10·3	1·2	0·6	3·6
Wheat 7	61·1	19·1	7·7	10·5	1·3	0·7	4·8
1898 *Surface Soils.*							
Barley 1	64·4	15·0	5·7	12·7	1·4	0·7	4·0
Wheat 1	63·7	14·0	11·0	9·7	1·7	0·7	3·5
1927 *Barley Surface Soils.*							
1	66·7	13·8	8·0	10·0	1·0	0·5	2·7
2a	54·6	27·0	8·7	9·3	1·4	0·6	2·8
2b	51·7	26·2	10·3	10·7	1·1	0·5	3·0
3a	54·0	21·1	8·7	10·7	1·1	0·3	3·1
3b	52·8	23·5	9·0	11·0	1·0	0·2	3·4
4a	56·7	22·1	9·3	8·7	1·1	0·2	2·8
4b	55·0	24·7	9·5	9·3	0·8	0·3	4·0
5a	57·6	21·0	9·0	10·7	0·9	0·3	3·2
5b	46·8	29·6	10·7	11·0	1·0	0·5	3·3
6	57·8	19·0	11·0	10·0	1·1	0·5	3·1
7	46·4	29·8	11·7	10·5	1·1	0·5	3·0
11b	43·1	28·5	11·0	11·7	1·7	0·6	4·1
1927 *Barley Subsoils* (9–18 inches).							
1	64·1	14·4	6·3	12·7	0·9	0·3	2·5
2a	65·4	14·6	9·3	9·7	0·9	0·4	2·2
2b	61·4	16·1	8·0	12·5	1·1	0·4	2·6
3b	61·1	16·3	8·7	11·7	1·1	0·8	2·7
4a	69·6	11·4	8·7	8·3	0·9	0·1	2·3
5a	—	—	9·5	10·7	0·9	0·3	2·6
5b	60·6	16·7	10·5	10·3	1·2	0·4	2·7
6	55·6	19·0	11·5	12·3	1·3	0·5	2·7
7	43·7	31·3	12·7	11·3	1·1	0·4	2·6
11b	38·9	31·8	13·5	12·0	1·2	—	2·8

TABLE 116 (*continued*).

Plot.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Moisture.	Loss on Solution.	Loss on Ignition.
1927 *Wheat Surface Soils.*							
1	54·1	23·2	6·7	11·0	1·2	0·7	3·0
2a	61·2	20·0	6·0	10·3	0·9	0·6	3·0
2aa	48·1	28·3	9·3	11·5	1·2	1·0	3·4
2b	55·1	23·3	8·3	11·0	1·1	0·5	3·2
2bb	61·5	15·8	10·3	10·3	1·3	0·7	3·1
3a	64·2	15·6	8·5	10·3	1·2	1·0	3·2
3b	53·8	24·9	9·0	9·5	1·1	0·5	3·0
4	55·2	22·5	8·5	10·7	1·3	0·5	3·5
5a	62·7	15·8	8·3	10·5	1·0	0·6	3·3
5b	54·9	21·0	8·5	11·3	1·1	0·4	1·8
6	57·8	22·9	10·7	10·0	1·5	0·5	3·3
7	58·6	18·8	12·0	9·5	1·1	0·4	3·7
11b	50·0	24·3	8·5	13·3	1·3	0·9	3·9
1927 *Wheat Subsoils* (9–18 inches).							
1	63·0	16·3	9·0	10·0	0·9	0·3	3·4
2a	57·8	23·6	7·5	8·7	0·8	0·4	2·3
2aa	49·4	29·3	9·3	10·0	1·0	0·3	2·8
2b	54·3	21·1	6·7	12·3	1·0	1·2	3·2
3b	54·1	25·8	8·5	10·0	1·0	0·9	2·5
4	47·5	28·1	8·3	14·0	1·3	0·5	3·1
5a	56·6	23·3	9·7	11·7	0·9	0·6	3·4
5b	60·5	19·0	9·0	10·5	1·0	0·5	2·5
6	55·4	24·6	9·5	10·5	0·9	0·3	2·6
7	50·3	27·3	10·0	10·5	1·0	0·5	2·5
11b	54·5	20·4	11·3	11·7	1·0	0·4	2·9

APPENDIX.

TABLE 117.—CONVERSIONS.

1 pound	=	0·453	Kilogramme.
1 acre	=	0·405	Hectare.
1 pound per acre	=	1·12	Kilogramme per Hectare.
1 cwt.	=	50·08	Kilogrammes.
1 cwt. per acre	=	126	Kilogrammes per Hectare.[1]
4 pecks	=	1	Bushel.
1 bushel	=	0·364	Hectolitre (36·364 litres).
1 bushel per acre [2]	=	0·90	Hectolitre per Hectare.
1 inch	=	25·40	Millimetres.

PRIMARY DATA.

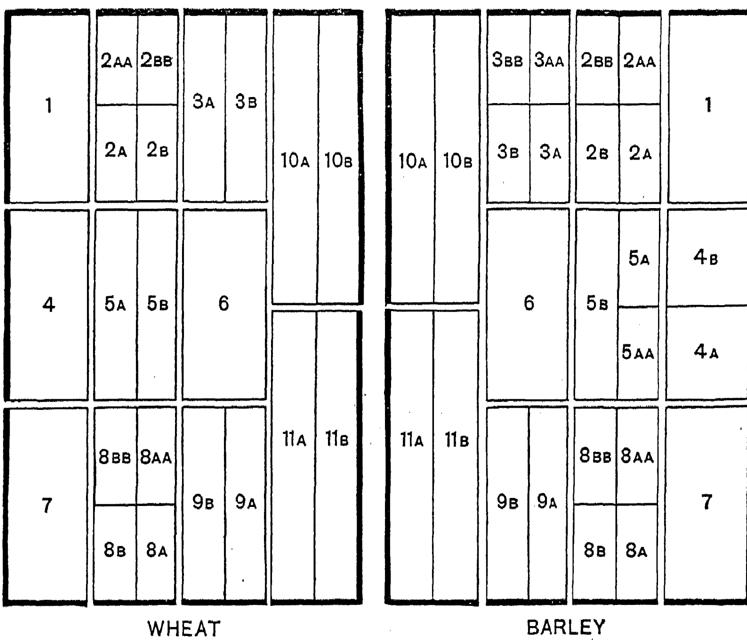


FIG. 42.—Plan of the continuous plots.

[1] 1·256 dz. per hectare.

[2] The bushels referred to above are Imperial bushels. The Winchester bushel used in America is rather different. 1 Winchester bushel = 35·236 litres. 1 Imperial bushel = 1·032 American bushels.

These figures are taken direct from the Recorder's notebooks, and in case of discrepancy with the text these are to be regarded as the correct values.

TABLE 118.—DATES OF SOWING AND VARIETIES OF SEED.

	Wheat.			Barley.	
1877	Nov.	1st week.	Browick Wheat.	Date not recorded.	Variety not recorded.
78	,,	5	Browick Wheat.	Mar. 6	,, ,, ,,
79	,,	2	,, ,,	,, 18	,, ,, ,,
1880	,,	13	,, ,,	,, 20	,, ,, ,,
81	Oct.	22	,, ,,	Apr. 11	Chevalier.
82	,,	18	,, ,,	Mar. 25	,,
83	,,	19	,, ,,	,, 31	Oakshott's Golden Melon.
84	,,	22	,, ,,	,, 20	Oakshott's Golden Melon.
85	,,	21	,, ,,	,, 28	Oakshott's Golden Melon.
86	,,	14	,, ,,	Apr. 10	Golden Melon.
87	,,	13	,, ,,	Mar. 22	,, ,,
88	,,	13	,, ,,	Apr. 4	Variety not recorded.
89	Nov.	7	,, Red.	Mar. 13	Webb's Melon.
1890	Oct.	24	,, ,,	Apr. 2	Golden Melon.
91	,,	16	,,	Mar. 26	,, ,,
92	Nov.	4	White-chaffed Browick.	,, 30	,, ,,
93	Oct.	17	,, ,, ,,	,, 23	,, ,,
94	,,	14	,, ,, ,,	,, 27	,, ,,
95	,,	18	,, ,, ,,	Apr. 1	,, ,,
96	,,	28	,, ,, ,,	,, 2	,, ,,
97	,,	3	,, ,, ,,	,, 10	,, ,,
98	,,	12	Stand Up.	Feb. 26	,, ,,
99	Nov.	4	White-chaffed Browick.	Mar. 17	Archer's Stiff-straw
1900	Oct.	25	,, ,, ,,	,, 28	,, ,,
01	,,	24	Street's Imperial.	Apr. 17	Standwell.
02	,,	18	White Monarch.	Mar. 22	Hallett's Pedigree.
03	,,	21	Grey-chaffed Browick.	,, 20	Standwell.
04	Nov.	1	Square-Head's Master.	,, 24	Chevalier.
05	Oct.	14	,, ,, ,,	,, 10	,,
06	,,	11	,, ,, ,,	Apr. 4	,,
07	,,	20	,, ,, ,,	Mar. 20	,,
08	Nov.	5	,, ,, ,,	,, 24	,,
09	Oct.	15	Street's Imperial.	Apr. 12	Goldthorpe.
1910	Nov.	9	Square-Head's Master.	Mar. 22	,,
11	Oct.	15	,, ,, ,,	Apr. 10	,,
12	Nov.	2	,, ,, ,,	,, 9	,,
13	Oct.	25	Webb's Red Standard.	Mar. 31	Chevalier.
14	,,	17	Square-Head's Master.	Apr. 4	,,
15	,,	27	Red Standard.	Mar. 31	,,
16	,,	29	,, ,,	Apr. 13	,,
17	,,	25	,, ,,	,, 23	,,
18	,,	26	Little Joss.	Mar. 26	,,
19	,,	24	,, ,,	Apr. 19	,,
1920	Nov.	5	,, ,,	,, 7	Plumage.
21	Oct.	15	Yeoman.	,, 21	Chevalier.
22	,,	10	Red Standard.	,, 18	Plumage Archer.
23	,,	26	,, ,,	,, 5	,, ,,
24	,,	19	,, ,,	Mar. 10	,, ,,
25	Nov.	18	Yeoman.	Apr. 17	,, ,,
26	Oct.	14	,,	,, 9	,, ,,

TABLE 119.—MANURES: CONTINUOUS WHEAT AND BARLEY.

Plot.		Manures Applied.
1		Unmanured.
2a		Sulphate of ammonia[1] (41 lb. nitrogen till 1906, 20·5 lb. since).
2aa	*Wheat.*	As 2a with 5 cwt. lime, Jan. 1905; repeated 1909–10–11.
	Barley.	As 2a with 5 cwt. lime, Mar. 1905; repeated 1909–10–12.
2b	*Wheat.*	As 2a with 2 tons lime, Dec. 1897.
	Barley.	As 2a with 2 tons lime, Dec. 1897; repeated 1912.
2bb	*Wheat.*	As 2b with further 2 tons lime, Jan. 1905.
	Barley.	As 2b with further 2 tons lime, Mar. 1905.
3a		Nitrate of soda (= 41 lb. nitrogen).
3b		Nitrate of soda (= 20·5 lb. nitrogen), since 1907 only.
4	*Wheat.*	Mineral manures.
4a	*Barley.*	Mineral manures.
4b	*Barley.*	As 4a, with 1 ton lime, Mar. 1915.
5a		Mineral manures and sulphate of ammonia as 2a.
5aa	*Barley.*	As 5a with 1 ton lime, Mar. 1905; repeated 1916.
5b	*Wheat.*	As 5a with 1 ton lime, Jan. 1905.
	Barley.	As 5a with 2 ton lime, Nov. 1897; repeated 1912.
6		Mineral manures and nitrate of soda (= 41 lb. nitrogen till 1906; 20·5 lb. since).
7		Unmanured.
8a		Mineral manures, sulphate of ammonia (= 82 lb. nitrogen till 1906; 41 lb. since) in alternate years, beginning with 1883.
8aa	*Wheat.*	As 8a with 10 cwt. lime, Jan. 1905; repeated Jan. 1918.
	Barley.	As 8a with 2 tons lime, Dec. 1897; repeated 1912.
8b		Mineral manures, sulphate of ammonia as 8a yearly till 1882, omitted in 1883 and alternate years since.
8bb	*Wheat.*	As 8b with 10 cwt. lime, Jan. 1905; repeated Jan. 1918.
	Barley.	As 8b with 2 tons lime, Dec. 1897; repeated 1912.
9a		Mineral manures, nitrate of soda as 9 (= 82 lb. nitrogen till 1906; 41 lb. since) in alternate years, beginning with 1883.

[1] Till 1907 ammonia salts (equal weights of sulphate and muriate of ammonia) were applied; since 1907 sulphate of ammonia only has been used.

Minerals for first 30 years were: 3½ cwt. superphosphate, 200 lb. sulphate of potash, 100 lb. sulphate of soda, 100 lb. sulphate of magnesia per acre. Since 1906, 3 cwt. superphosphate and ½ cwt. sulphate of potash only.

TABLE 119.—MANURES: CONTINUOUS WHEAT AND BARLEY (*continued*).

Plot.		Manures Applied.
9b		Mineral manures, nitrate of soda as 9a yearly till 1882, omitted in 1883 and alternate years since.
10a		Farmyard manure (= 53 lb. nitrogen), 1877–81; unmanured, 1882–1906 (except rape cake in 1889 as 10b); superphosphate, 3 cwt. nitrate of soda (= 20·5 lb. nitrogen), 1907–26.
10b		Farmyard manure (= 53 lb. nitrogen), 1877–87; unmanured, 1888; rape cake, 1889–1906 (= 41 lb. nitrogen in 1889; 82 lb. thereafter); rape-dust (= 20·5 lb. nitrogen), 1907–26.
11a		Farmyard manure (= 105 lb. nitrogen), 1877–87; unmanured, 1882–1906; sulphate of potash, 1 cwt. nitrate of soda (20·5 lb. nitrogen), 1907–26.
11b[1]		Farmyard manure (105 lb. nitrogen till 1906, 82 lb. since).

[1] Woburn Permanent Wheat and Barley: Method of applications of dung.

1877–1888—	Wheat:	top-dressing in Feb.
	Barley:	ploughed-in in Feb.
1889–1906—	Wheat:	top-dressing in Feb.
	Barley:	,, ,, ,, Mar. or Apr.
1907–1926—	Wheat:	ploughed-in in Oct.
	Barley:	,, ,, Mar.

TABLE 120.—CONTINUOUS BARLEY. GRAIN, LB. PER ACRE. DRESSED GRAIN TO 1896: TOTAL GRAIN THEREAFTER.

Year.	Plot 1.	Plot 2a.	Plot 2aa.	Plot 2b.	Plot 2bb.	Plot 3a.	Plot 3aa.	Plot 3b.	Plot 3bb.	Plot 4a.	Plot 4b.	Plot 5a.	Plot 5aa.	Plot 5b.	Plot 6.	Plot 7.	Plot 8a.	Plot 8aa.	Plot 8b.	Plot 8bb.	Plot 9a.	Plot 9b.	Plot 10a.	Plot 10b.	Plot 11a.	Plot 11b.
1877	1207·7	1932·5	—	—	—	1460·5	—	—	—	991·8	—	2129·1	—	—	1816·0	1086·5	2950·9	—	—	—	2744·5	—	—	1006·4	—	1436·3
78	1224·0	1864·8	—	—	—	1631·8	—	—	—	1204·0	—	1849·7	—	—	2142·8	959·2	2589·4	—	—	—	2464·0	—	—	1096·4	—	1532·5
79	958·8	1368·6	—	—	—	1053·5	—	—	—	625·4	—	1492·4	—	—	1425·1	663·0	1586·2	—	—	—	1850·0	—	—	946·4	—	1414·4
1880	1706·3	2060·0	—	—	—	2345·2	—	—	—	1153·6	—	2635·5	—	—	2567·3	1089·9	2537·6	—	—	—	2167·6	—	—	1724·3	—	2386·8
81	1677·7	2229·5	—	—	—	2430·5	—	—	—	1629·6	—	2285·0	—	—	2675·7	1613·5	2670·9	—	—	—	2840·0	—	—	2253·4	—	2651·6
82	1723·1	2307·2	—	—	—	2594·6	—	—	—	1201·2	—	2589·4	—	—	2737·1	1380·5	2756·2	—	2020·7	—	3440·2	1986·9	2090·9	2132·7	2056·7	2211·2
83	1596·8	2681·8	—	—	—	2708·3	—	—	—	1470·0	—	2809·7	—	—	2946·2	1279·7	3368·8	—	1911·4	—	3124·2	1945·8	1743·5	2039·0	1981·5	2616·3
84	1747·4	2805·8	—	—	—	2801·9	—	—	—	1714·1	—	2927·2	—	—	3179·0	1754·9	3320·8	—	2612·3	—	2975·0	2079·5	2341·8	2317·1	2586·3	3203·3
85	1100·9	1683·6	—	—	—	1893·5	—	—	—	1043·7	—	2520·0	—	—	2751·4	1113·8	3040·7	—	2035·7	—	3489·5	1809·6	1219·5	1546·2	2075·0	2005·6
86	996·5	1573·4	—	—	—	2023·7	—	—	—	974·3	—	1730·2	—	—	2146·7	917·3	2354·9	—	1402·0	—	2802·8	1476·4	1393·7	1022·4	1331·3	1840·7
87	1074·6	1621·1	—	—	—	1599·5	—	—	—	1140·4	—	1778·9	—	—	2352·1	1077·9	2343·5	—	1631·0	—	2845·7	1413·8	1368·7	1344·2	1941·9	1779·7
88	919·5	2216·1	—	—	—	1928·4	—	—	—	1029·1	—	2444·6	—	—	2433·4	843·2	2644·0	—	1858·6	—	2450·0	1508·7	1272·1	1263·6	1922·2	1503·4
89	572·4	1512·0	—	—	—	1424·2	—	—	—	685·1	—	1773·3	—	—	1795·7	665·5	2168·4	—	1193·6	—	1962·1	959·3	1117·1	998·3	1270·1	1460·6
1890	1557·6	2122·6	—	—	—	2026·6	—	—	—	1738·8	—	2696·2	—	—	2797·8	1291·5	2813·0	—	1854·6	—	2775·6	2274·6	1632·8	2029·3	1952·0	2771·3
91	1050·7	1633·3	—	—	—	1465·1	—	—	—	1398·9	—	2043·6	—	—	2197·8	986·7	2469·8	—	2185·2	—	2456·4	1842·6	1168·7	2430·5	1596·8	2081·6
92	948·1	1808·5	—	—	—	2182·8	—	—	—	1628·3	—	2623·1	—	—	2900·4	1188·3	3022·8	—	1623·4	—	3104·6	1869·0	1317·1	2503·4	1669·5	2866·9
93	740·6	749·0	—	—	—	1042·1	—	—	—	885·1	—	1059·3	—	—	1234·2	737·1	1094·8	—	1229·8	—	1458·0	1163·9	882·9	1166·3	1262·1	1716·8
94	945·4	1466·6	—	—	—	2159·7	—	—	—	1225·3	—	2606·4	—	—	2613·3	1163·9	2575·5	—	1803·5	—	2605·5	2089·5	1445·9	2603·4	1910·0	2803·4
95	411·7	739·4	—	—	—	929·4	—	—	—	779·2	—	839·5	—	—	1616·0	710·6	619·5	—	930·6	—	1676·8	1164·1	1030·2	1561·6	1372·2	1775·0
96	520·2	580·8	—	—	—	1040·3	—	—	—	702·8	—	836·6	—	—	1607·3	572·3	918·2	—	486·7	—	1751·6	1307·0	744·5	1203·2	1113·8	1768·8
97	300·5	491·4	—	—	—	1122·9	—	—	—	556·4	—	661·7	—	—	1789·4	389·3	691·6	—	609·7	—	1978·7	1054·1	546·3	1375·1	781·6	1625·2
98	606·8	419·5	—	917·6	—	1241·3	—	—	—	976·6	—	253·4	—	1978·3	2060·8	799·3	1230·8	2102·7	1107·7	1512·3	2373·7	1637·4	793·0	1967·5	1102·3	2192·5
99	711·3	300·6	—	1654·0	—	1747·6	—	—	—	1030·6	—	332·4	—	2260·0	2714·6	916·5	1345·2	2694·6	1239·5	2104·5	3046·1	1551·3	1289·8	2124·7	1639·1	2566·1
1900	452·0	344·0	—	1559·7	—	1268·0	—	—	—	911·0	—	670·2	—	1856·0	1778·9	778·7	1272·0	2505·4	737·0	1313·2	2045·1	1144·2	735·6	1710·6	1010·8	1599·2
01	766·9	430·4	—	930·6	—	1107·1	—	—	—	927·5	—	861·9	—	1319·3	1530·2	783·5	845·0	1612·8	780·2	1326·5	1823·0	1262·5	935·1	1291·6	1188·2	1771·4
02	1435·1	49·6	—	1610·1	—	2124·5	—	—	—	1812·7	—	688·2	—	2919·6	2275·1	1222·3	1170·5	2828·0	1840·8	3030·3	2835·6	1956·5	1645·0	2665·2	1799·1	2800·1
03	93·0	69·6	—	286·0	—	549·2	—	—	—	68·0	—	69·6	—	629·3	1293·2	111·6	365·0	1349·5	165·2	762·4	2211·7	717·5	351·2	1480·2	663·8	1361·3
04	164·0	44·4	—	747·3	—	599·6	—	—	—	294·6	—	99·2	—	1264·8	1323·0	314·5	373·6	1676·6	155·2	586·4	2052·5	770·2	405·2	1357·3	627·0	1346·7

05	1113·0	—	550·0	1329·4	1684·9	1009·1	—	—	—	1306·6	—	218·8	210·8	2292·5	1692·0	1043·8	194·6	2133·5	363·2	2039·2	1847·0	1020·1	1263·8	1955·4	1813·4	2431·2
06	661·9	—	576·8	1406·2	2128·8	1997·6	—	—	—	993·8	—	91·4	1929·5	2462·4	2594·0	925·0	676·8	2122·3	180·8	1545·5	3305·9	1802·7	1233·2	2455·9	1447·8	2563·7
07	1108·0	—	730·0	1388·0	1510·1	1904·9	—	1618·6	—	883·0	—	359·0	2469·4	1601·7	1893·9	994·8	786·4	2045·1	336·8	1134·4	2336·1	1532·8	1209·0	1740·7	1844·3	2467·4
08	356·1	—	—	174·4	552·4	961·7	—	791·3	—	297·1	—	—	740·8	346·8	765·7	290·1	—	708·0	—	364·8	1183·0	544·2	992·6	768·6	1055·5	1330·5
09	424·0	—	363·2	627·0	1741·8	1037·9	—	1016·2	—	444·3	—	136·8	1766·8	1588·4	1549·2	415·0	361·7	1486·3	261·6	911·4	1824·2	1191·8	1213·2	1301·6	1983·4	2457·7
1910	215·8	—	202·0	268·4	217·6	618·0	—	354·8	—	496·0	—	286·8	1125·5	816·0	766·5	168·0	363·6	863·2	—	473·6	1784·1	855·6	741·5	706·7	1053·4	969·4
11	219·0	—	315·0	220·0	135·6	204·0	—	97·0	—	389·0	—	—	203·2	206·4	231·9	81·0	—	244·0	—	280·0	344·5	217·5	141·0	240·6	357·0	1430·3
12	499·2	196·8	421·0	843·0	788·0	417·0	—	578·0	—	1081·9	—	363·2	1199·0	1459·2	1099·6	499·6	285·0	1716·7	211·0	1165·0	1134·7	1030·1	942·2	971·3	1215·6	1318·1
13	370·8	—	648·8	1811·0	907·8	841·8	—	784·9	—	650·1	—	—	739·4	1684·9	1187·1	318·0	—	1862·3	—	1559·8	1615·9	1037·7	1308·8	1239·9	1595·5	2178·5
14	963·1	216·4	385·0	1174·2	553·0	647·7	—	864·3	—	1066·0	—	—	867·0	1414·9	988·6	645·7	—	1144·6	—	1012·8	1066·0	721·0	1303·0	976·0	1150·1	1314·3
15	509·7	66·0	269·8	404·8	358·0	446·0	—	467·9	—	626·8	1063·8	124·0	449·2	842·4	859·1	615·6	163·2	1035·1	94·0	778·4	695·5	819·8	624·0	432·6	758·5	1515·9
16	711·5	79·0	448·8	846·0	1125·5	1211·4	—	924·3	—	867·3	869·3	390·3	1253·9	1200·4	1318·2	525·2	—	1274·9	—	561·1	1618·3	920·3	1387·3	1080·0	1447·8	1692·7
17	785·6	—	549·2	569·8	758·1	930·5	—	857·1	—	902·5	1021·3	219·6	1364·8	1035·0	1222·5	711·7	236·3	1195·1	—	1052·8	1339·0	802·4	1225·2	828·4	1276·7	1332·3
18	487·5	—	297·9	857·0	373·7	995·0	—	393·2	—	335·2	496·0	—	781·3	912·5	1100·9	421·0	127·1	1161·6	—	579·3	1428·2	929·8	1255·0	507·8	1362·6	1889·8
19	649·3	127·2	354·4	381·7	340·8	564·7	—	526·8	—	734·0	962·7	502·7	980·2	711·0	1009·2	583·6	138·0	839·3	138·0	685·0	1238·4	672·0	963·0	641·0	1393·3	1508·8
1920	428·7	162·1	228·0	241·5	500·0	587·8	—	351·3	—	848·0	526·2	248·0	845·0	887·8	888·6	391·5	72·0	945·5	52·0	537·0	1044·1	761·8	946·1	688·1	1310·8	1792·7
21	304·8	60·0	65·0	340·6	144·8	227·0	229·0	244·1	247·8	457·2	567·3	246·8	432·4	246·8	529·1	267·0	121·6	524·0	122·9	433·6	644·1	671·2	518·0	320·6	546·8	1076·2
22	756·6	264·6	352·8	1177·5	1196·8	609·4	1117·6	865·9	1060·5	918·6	989·2	704·0	1475·4	1344·0	1501·6	633·6	100·0	1331·9	65·0	817·9	1674·7	1358·1	1225·7	555·2	1469·9	1977·7
23	217·3	—	93·6	170·4	170·3	583·7	417·6	254·0	246·8	295·2	318·3	117·7	327·3	342·8	433·3	196·4	—	460·4	—	335·6	685·2	311·8	297·2	288·0	606·5	1163·4
24	94·2	—	254·8	213·1	181·3	256·5	180·4	229·9	234·0	106·6	234·0	—	553·4	362·6	654·2	82·8	—	712·9	—	340·6	443·8	296·7	439·5	137·5	348·4	682·0
25	442·2	—	348·2	323·3	228·0	455·6	225·1	401·3	250·1	378·8	409·6	—	415·0	546·0	463·9	336·9	—	640·0	—	401·1	614·9	553·8	350·8	205·6	396·6	940·7
26	177·2	221·0	287·2	253·6	537·6	757·6	367·6	345·6	391·2	252·0	450·4	632·0	995·0	548·0	819·5	119·2	156·0	259·2	138·4	550·0	1229·7	570·8	345·2	393·2	590·6	1372·4

TABLE 121.—CONTINUOUS BARLEY. TOTAL PRODUCE, LB. PER ACRE.

Year.	Plot 1.	Plot 2a.	Plot 2aa.	Plot 2b.	Plot 2bb.	Plot 3a	Plot 3aa.	Plot 3b.	Plot 3bb.	Plot 4a.	Plot 4b.	Plot 5a.	Plot 5aa.	Plot 5b.	Plot 6.	Plot 7.	Plot 8a.	Plot 8aa.	Plot 8b.	Plot 8bb.	Plot 9a.	Plot 9b.	Plot 10a.	Plot 10b.	Plot 11a.	Plot 11b.
1877	2762	4564	—	—	—	3616	—	—	—	2266	—	4985	—	—	4323	2430	6899	—	—	—	6343	—	—	2253	—	3172
78	3032	4505	—	—	—	4294	—	—	—	2940	—	5103	—	—	5374	2336	6861	—	—	—	6839	—	—	2940	—	3716
79	2448	3396	—	—	—	3006	—	—	—	1757	—	3906	—	—	3775	1901	4188	—	—	—	4886	—	—	2408	—	3144
1880	3666	4444	—	—	—	5319	—	—	—	2174	—	5668	—	—	6123	2562	5996	—	—	—	6221	—	—	3949	—	5012
81	3581	4599	—	—	—	5169	—	—	—	3236	—	4859	—	—	5970	3249	5764	—	—	—	6324	—	—	4883	—	5799
82	4002	5612	—	—	—	6134	—	—	—	2961	—	6384	—	—	6793	3609	8458	—	4846	—	8915	4135	4267	4777	4455	5034
83	3683	6074	—	—	—	6885	—	—	—	3422	—	6447	—	—	7834	2842	6989	—	4123	—	8709	4425	3716	4607	4777	6465
84	3583	5748	—	—	—	6006	—	—	—	3560	—	6031	—	—	7331	3857	7773	—	5560	—	8339	4287	5198	4593	5350	6915
85	2407	4164	—	—	—	4223	—	—	—	2206	—	5363	—	—	5837	2355	6691	—	4150	—	7928	3522	2696	3282	4215	4447
86	2377	3328	—	—	—	4403	—	—	—	2119	—	3520	—	—	4709	1945	5038	—	3106	—	6407	3152	3162	2298	3054	3413
87	2340	3381	—	—	—	3580	—	—	—	2542	—	3996	—	—	5226	2274	4996	—	3415	—	6509	2837	2959	2726	4032	3698
88	2150	4846	—	—	—	4424	—	—	—	2152	—	5175	—	—	5322	1772	6082	—	4124	—	5808	3092	2916	2847	4090	3226
89	1277	3002	—	—	—	3131	—	—	—	1326	—	3380	—	—	4196	1397	5429	—	2242	—	5701	1959	2569	2197	2710	2957
1890	3184	4295	—	—	—	4385	—	—	—	3290	—	5246	—	—	5727	2641	6011	—	3863	—	6298	4659	3300	4529	4092	5757
91	2426	3669	—	—	—	3828	—	—	—	2890	—	4827	—	—	5651	2236	6390	—	4759	—	6791	4032	2765	5594	3767	5052
92	2171	3699	—	—	—	4795	—	—	—	3211	—	5234	—	—	6432	2574	6174	—	3410	—	7155	4033	2890	5178	3672	6097
93	1637	1710	—	—	—	2237	—	—	—	1935	—	2421	—	—	2655	1559	2342	—	2484	—	3142	2506	1875	2482	2698	3597
94	2237	3087	—	—	—	4829	—	—	—	2380	—	5452	—	—	6388	2438	6628	—	3965	—	7666	4444	2986	5872	4182	6110
95	1016	1538	—	—	—	2042	—	—	—	1677	—	1826	—	—	3447	1509	1345	—	2298	—	3563	2636	2208	3249	3006	3761
96	1402	1657	—	—	—	2589	—	—	—	1805	—	2265	—	—	4067	1580	2362	—	1401	—	4295	3315	1969	3263	2830	4528
97	816	1375	—	—	—	2821	—	—	—	1386	—	1813	—	—	4312	908	1634	—	1604	—	4715	2436	1246	3378	1889	3685
98	1604	946	—	2320	—	3066	—	—	—	2111	—	679	—	4644	4772	1857	2802	4769	2365	3768	5463	3592	1972	4947	2512	5454
99	1373	685	—	3229	—	3625	—	—	—	2058	—	775	—	4192	5384	1801	2490	5109	2417	3956	6135	2980	2563	4309	3362	5198
1900	1093	773	—	3149	—	2806	—	—	—	1836	—	1380	—	3764	3917	1565	2522	5362	1536	2449	4624	2260	1533	3777	2282	3560
01	1584	1006	—	1858	—	2145	—	—	—	1999	—	1603	—	2644	3220	1520	1868	3354	1786	2589	3718	2548	1926	2707	2462	3806
02	2724	827	—	3184	—	4491	—	—	—	3215	—	2364	—	6474	5500	2364	3375	6720	3675	5567	6660	4078	3235	5938	3831	5991
03	351	235	—	1018	—	1572	—	—	—	302	—	239	—	1668	3081	382	965	3078	413	1679	5228	1665	962	3010	1456	2990
04	506	99	—	1572	—	1342	—	—	—	729	—	255	—	3031	3068	730	861	3796	387	1230	4863	1595	919	3147	1346	2920
05	2459	62	1334	2969	3873	2354	—	—	—	2802	—	559	519	5049	3886	2224	459	4753	863	4427	4227	2280	2564	4516	3620	5361

06	1460	28	1233	2570	4209	4196	—	—	—	2076	—	184	3722	4848	5618	1893	1414	4446	471	3261	8045	3862	2639	5190	3123	5608
07	2379	—	1642	3064	3391	4587	—	3686	—	1888	—	842	5277	3473	4231	2111	2035	4609	639	2214	5263	3128	3308	3952	4055	4907
08	889	—	197	601	1226	2100	—	1748	—	829	—	52	1567	790	1578	704	88	1796	—	985	2390	1244	2052	1632	2188	2711
09	1350	64	1128	1968	3498	3333	—	2646	—	1878	—	346	4582	4233	4327	1299	877	3593	713	2700	5902	2931	3399	3225	5881	6613
1910	875	68	976	777	1080	1811	—	976	—	1276	—	721	2737	2001	1762	636	677	2120	44	1062	3933	1551	1678	1599	2362	2233
11	664	—	923	592	495	566	—	417	—	1026	—	—	1011	800	862	376	—	788	—	736	1312	556	841	712	1431	3179
12	1392	467	1589	1971	1828	1697	—	1648	—	2607	—	1423	3101	3633	3064	1321	655	4214	759	3143	3517	2944	2585	2620	3151	3700
13	895	60	1605	3839	1988	1938	—	1865	—	1510	—	76	1724	3537	2650	769	93	4014	64	3319	3375	2280	2937	2724	3514	4836
14	2326	342	933	2952	1375	1888	—	2311	—	2649	—	—	2237	3540	2655	1698	113	2978	77	2435	3150	1916	3150	2439	3150	3406
15	1452	179	718	1278	974	1406	—	1318	—	1453	2362	450	1287	2064	2286	1448	309	2538	240	1898	2488	1962	1635	1254	1975	3541
16	1870	244	1182	2313	2714	3468	—	2486	—	2059	2234	1616	3389	2988	3404	1399	—	3184	—	1653	4497	2391	3643	2560	4090	4528
17	2019	242	1533	1867	2027	2378	—	2140	—	2007	2361	607	2936	2310	2677	1616	579	2618	197	2398	2969	1806	2727	1917	2927	3362
18	1193	174	665	1965	849	2225	—	813	—	1022	1218	246	1619	1978	2248	889	268	2407	48	1358	2983	1865	2620	1295	2909	4128
19	1466	374	1060	974	1078	1374	—	1203	—	1528	1955	1148	2443	1594	2243	1383	331	2149	307	1354	2688	1490	2281	1515	3028	3211
1920	1215	346	796	545	1516	1606	—	1038	—	2011	1325	780	2234	2041	2321	1032	280	2302	172	1204	2628	2024	2466	1964	3276	4700
21	936	156	241	1061	697	707	717	732	784	1422	1397	550	1293	662	1371	637	297	1404	299	1426	1776	1666	1136	886	1486	2568
22	1951	585	949	2657	2424	1378	2914	1854	2196	2148	2265	1748	3076	3108	3302	1598	196	3224	177	2346	3864	2972	2847	1400	3481	4182
23	1073	—	470	794	842	2152	1505	1206	1179	921	1227	494	1256	1315	1647	878	—	1389	—	1320	2497	1320	1094	960	1762	3179
24	460	—	1171	841	894	1257	1008	1098	1198	426	630	—	1765	968	1748	471	—	1929	—	1056	1251	834	1350	698	1054	1708
25	1231	—	948	1003	572	1272	650	1265	514	869	1158	—	1375	1434	1144	1197	—	1848	—	1089	1982	1516	1127	605	1165	2621
26	538	422	1267	1170	1757	1898	1259	1237	1394	886	1687	1844	2151	1506	2136	488	423	1140	369	1810	3009	2057	1310	1495	1627	4002

TABLE 122.—CONTINUOUS WHEAT. GRAIN, LB. PER ACRE. DRESSED GRAIN TO 1896: TOTAL GRAIN THEREAFTER.

Year.	Plot 1.	Plot 2a.	Plot 2aa.	Plot 2b.	Plot 2bb.	Plot 3a.	Plot 3b.	Plot 4.	Plot 5.	Plot 5a.	Plot 5b.	Plot 6.	Plot 7.	Plot 8a.	Plot 8aa.	Plot 8b.	Plot 8bb.	Plot 9a.	Plot 9b.	Plot 10a.	Plot 10b.	Plot 11a.	Plot 11b.
1877	1365·8	2101·1	—	—	—	1933·1	—	1258·7	2064·5	—	—	1929·6	1277·0	2695·1	—	—	—	2392·9	—	—	1080·0	—	1141·6
78	948·0	1052·1	—	—	—	695·0	—	651·0	777·4	—	—	841·4	703·2	1660·5	—	—	—	1657·4	—	—	772·0	—	1006·5
79	489·9	752·6	—	—	—	602·4	—	540·5	1479·7	—	—	1402·5	375·0	1597·4	—	—	—	1407·1	—	—	737·0	—	1032·2
1880	486·7	569·3	—	—	—	490·4	—	775·7	1292·8	—	—	1202·7	683·2	1459·8	—	—	—	1317·4	—	—	762·6	—	1008·6
81	1470·0	1743·5	—	—	—	2238·6	—	1604·6	2320·5	—	—	2712·0	1490·0	2616·0	—	—	—	2913·4	—	—	1992·6	—	2472·0
82	703·6	1865·6	—	—	—	1489·8	—	841·9	2092·0	—	—	1928·6	732·6	2566·5	—	771·4	—	2105·0	683·2	868·9	946·2	895·1	1252·8
83	942·4	1402·6	—	—	—	1498·6	—	1010·3	2007·5	—	—	2232·7	1087·8	2761·7	—	996·5	—	2531·6	1097·4	1186·0	1665·6	1291·1	2026·8
84	1362·9	2337·4	—	—	—	1796·0	—	1274·4	2707·3	—	—	2527·8	1574·7	2879·2	—	1940·3	—	2952·9	1257·1	1435·7	1722·8	1379·4	2223·0
85	1175·8	1765·9	—	—	—	1568·0	—	1243·2	2216·3	—	—	2279·5	1211·1	2371·5	—	1464·7	—	2312·0	1053·0	1127·1	1507·5	1193·1	1898·5
86	685·6	916·3	—	—	—	1080·0	—	914·8	1278·1	—	—	1823·4	804·8	2084·5	—	830·7	—	1996·7	894·0	929·9	1027·5	929·6	1595·9
87	1286·5	1542·5	—	—	—	2072·0	—	1065·5	1695·9	—	—	2375·8	1375·1	2051·3	—	1515·2	—	2527·3	1201·8	1510·1	1715·4	1581·9	2099·6
88	667·5	890·9	—	—	—	966·8	—	601·4	1352·8	—	—	1615·7	474·7	1592·5	—	1056·4	—	1506·0	685·1	683·7	932·9	828·4	1334·0
89	775·5	1554·3	—	—	—	1041·4	—	728·3	2126·5	—	—	1769·0	779·8	2575·2	—	1240·2	—	1810·6	640·7	1156·3	1413·7	919·6	1796·5
1890	827·7	1442·5	—	—	—	1725·4	—	899·4	1824·1	—	—	1964·2	915·3	2347·8	—	1567·8	—	2356·1	1066·5	1049·0	1830·1	1180·1	1731·7
91	846·8	1655·9	—	—	—	1452·0	—	974·1	1942·2	—	—	2416·8	926·6	2734·6	—	1316·3	—	1861·8	1075·0	1077·3	2054·1	1275·2	2192·7
92	628·3	1566·6	—	—	—	857·5	—	697·2	1485·5	—	—	1230·8	865·8	1983·6	—	978·8	—	1144·6	889·2	628·7	1380·5	827·0	1424·4
93	556·3	577·5	—	—	—	700·0	—	608·6	829·2	—	—	827·9	762·3	1116·9	—	1028·3	—	1092·0	882·7	793·6	838·2	1163·7	1169·2
94	845·4	2728·3	—	—	—	2074·3	—	797·3	3329·3	—	—	2498·0	933·1	3550·2	—	3151·8	—	2171·5	1461·2	1239·9	2638·7	1268·0	1821·7
95	599·8	803·9	—	—	—	918·1	—	568·2	931·8	—	—	1234·1	673·2	1078·4	—	1057·4	—	1230·1	830·8	814·0	1089·4	867·2	1447·6
96	403·0	1270·9	—	—	—	1130·9	—	471·9	1766·1	—	—	1422·1	597·8	1939·8	—	1673·2	—	1502·2	728·4	731·9	1480·4	731·9	1303·8
97	488·9	795·3	—	—	—	727·3	—	537·1	1370·6	—	—	1192·2	513·8	1622·6	—	1100·7	—	1355·8	663·4	620·5	1469·8	576·9	1071·2
98	848·1	1733·4	—	1970·7	—	1250·5	—	753·8	2915·6	—	—	2076·4	913·9	3476·6	—	2592·8	—	2145·6	1065·4	1305·4	2460·1	1580·4	2400·6
99	619·6	1216·3	—	1790·1	—	1716·5	—	428·0	1831·8	—	—	1904·6	541·8	2106·6	—	1288·9	—	2530·8	608·9	926·2	1809·2	809·5	1259·4
1900	496·6	882·3	—	1098·9	—	960·6	—	383·0	1565·9	—	—	1398·5	527·6	1721·7	—	1058·5	—	1718·0	473·2	673·5	1516·3	604·2	1080·8
01	498·0	38·0	—	330·4	—	995·9	—	493·0	793·7	—	—	1261·3	486·8	324·4	—	574·6	—	1551·7	672·8	658·8	1271·7	780·8	1629·7
02	739·0	294·4	—	723·8	—	1425·5	—	677·8	1826·8	—	—	2120·8	1078·8	1621·4	—	1155·4	—	1802·8	1409·4	1260·2	2282·8	1507·9	2344·6
03	552·0	439·8	—	1043·8	—	1031·1	—	512·9	1432·4	—	—	1314·4	655·3	1372·9	—	964·4	—	2199·6	804·5	522·0	1522·4	580·0	1342·1
04	273·4	—	—	164·0	—	266·0	—	412·2	263·4	—	—	779·1	460·1	351·2	—	—	—	1037·7	336·0	307·8	897·3	558·8	758·6

05	306·4	—	—	665·0	585·2	742·0	—	606·8	—	1531·2	1270·7	1434·2	1004·9	544·0	917·0	660·0	1225·4	1759·1	1037·7	775·3	1350·1	1097·0	2166·6
06	611·3	206·4	1232·0	1665·2	1607·8	1482·6	—	435·4	—	2027·6	2028·5	1405·0	731·8	1784·0	2202·3	617·6	1371·1	2368·8	468·0	995·9	2229·5	880·3	1019·4
07	584·7	218·0	679·0	1556·2	979·8	1584·3	1074·9	585·2	—	2011·4	2139·9	1436·4	769·4	1137·4	2397·4	871·2	1542·5	1620·6	716·7	1417·8	1341·5	1054·0	1262·6
08	799·3	—	184·0	1429·5	1139·0	1529·1	1432·5	705·6	—	805·4	1142·4	1622·8	769·7	189·7	1107·2	214·5	820·0	1799·9	1035·9	1632·1	1052·9	1554·2	1526·6
09	498·3	—	—	939·0	790·6	1069·9	800·1	433·6	—	1213·7	1498·0	856·8	530·0	158·0	1221·5	197·6	1204·0	910·1	472·2	897·1	1460·5	690·4	1658·2
1910	855·7	—	736·8	1441·9	1334·3	1421·8	1226·1	796·6	—	1084·0	1496·8	1449·7	917·1	472·8	1427·3	312·2	774·0	1736·0	850·0	1396·2	1578·6	1302·8	1146·6
11	495·1	92·0	1219·3	818·4	669·2	1345·2	1347·6	454·3	—	509·2	963·3	1077·3	556·1	129·6	820·1	86·0	347·2	977·0	599·7	1080·4	1118·1	1244·2	1266·4
12	520·4	—	983·4	1041·8	787·2	492·8	544·0	465·0	—	1339·8	1405·2	551·4	423·2	598·4	1388·8	353·6	1232·7	461·2	344·3	858·8	1022·6	614·5	797·3
13	772·8	—	852·0	1034·3	963·2	1273·9	1052·8	745·0	—	789·5	1482·9	1427·3	922·1	379·2	920·0	—	720·0	1500·4	958·6	1179·0	1240·0	1133·9	1423·7
14	244·6	—	699·2	437·5	364·7	511·0	461·4	229·6	—	504·0	1226·2	439·3	364·3	—	640·0	—	292·0	534·6	177·0	667·8	774·0	400·4	837·8
15	820·1	—	1006·0	842·9	1020·8	1325·6	1138·4	753·1	—	1215·8	1325·2	1251·2	838·3	112·0	733·6	706·0	1375·3	1201·2	975·3	1220·5	1489·2	1149·4	1555·6
16	313·8	85·8	433·0	417·1	348·8	573·5	440·2	250·7	—	451·3	795·0	783·3	398·8	—	476·8	—	205·6	651·8	391·5	536·9	841·4	542·2	875·7
17	544·0	157·2	647·2	435·8	864·0	1276·8	1080·0	761·2	—	628·2	994·5	1701·0	751·3	112·0	296·0	274·8	443·0	1652·8	965·8	1360·4	909·0	1512·6	1612·5
18	759·7	—	976·5	1113·6	889·6	1177·8	1005·6	819·3	—	1249·4	1697·4	1280·8	819·5	661·0	1388·5	478·1	997·8	1370·9	588·3	890·9	1649·4	764·7	1553·1
19	423·2	—	436·4	363·1	718·4	868·7	857·0	600·7	—	495·4	726·8	952·5	497·9	146·6	597·6	350·0	656·8	1025·0	677·5	834·0	676·2	744·1	1340·2
1920	569·5	100·0	420·0	767·0	548·0	949·1	903·8	573·3	—	970·6	1145·2	1108·2	427·4	441·6	1059·6	186·0	1067·2	805·5	524·4	994·2	970·5	1006·1	979·9
21	365·5	—	338·8	484·0	617·8	1089·7	909·8	564·7	—	490·0	923·8	1270·7	643·5	432·4	712·8	317·1	673·0	1549·8	828·4	673·6	817·2	897·8	2121·5
22	539·3	84·0	540·0	602·0	570·0	821·2	810·0	468·0	—	872·1	1026·7	850·8	495·7	324·0	606·0	228·0	610·0	673·0	495·6	1110·0	831·5	716·0	652·8
23	326·4	—	377·0	130·0	215·8	727·6	662·0	546·9	—	94·0	401·6	799·0	386·4	101·0	180·2	78·4	396·0	615·0	233·9	739·9	553·2	659·0	737·4
24	102·8	—	202·0	153·2	376·9	844·0	821·8	203·5	—	228·0	357·2	854·6	80·4	—	384·8	—	228·0	834·2	311·0	951·2	551·4	999·0	967·8
25	114·0	—	—	83·2	71·6	405·8	338·4	62·0	—	—	69·2	189·6	114·0	135·9	334·0	—	—	240·0	133·8	133·6	309·6	163·3	361·0
26	327·0	—	261·2	649·8	475·2	927·7	549·4	354·2	—	643·3	916·2	608·0	315·5	—	376·0	—	96·0	437·6	408·2	586·6	342·0	544·2	357·6

TABLE 123.—CONTINUOUS WHEAT. TOTAL PRODUCE, LB. PER ACRE.

Year.	Plot 1.	Plot 2a.	Plot 2aa.	Plot 2b.	Plot 2bb.	Plot 3a.	Plot 3b.	Plot 4.	Plot 5a.	Plot 5b.	Plot 6.	Plot 7.	Plot 8a.	Plot 8aa.	Plot 8b.	Plot 8bb.	Plot 9a.	Plot 9b.	Plot 10a.	Plot 10b.	Plot 11a.	Plot 11b.
1877	3690	6273	—	—	—	5769	—	3499	6432	—	6060	3489	8114	—	—	—	7181	—	—	3167	—	3438
78	3136	3448	—	—	—	2879	—	2701	2870	—	3492	2812	6392	—	—	—	6445	—	—	2538	—	3270
79	1932	3071	—	—	—	2780	—	2467	5425	—	5513	1860	6711	—	—	—	6630	—	—	2865	—	3740
1880	1989	2275	—	—	—	2244	—	2946	4861	—	3904	2434	5049	—	—	—	5560	—	—	2950	—	3867
81	3681	4091	—	—	—	5320	—	3995	5694	—	6847	3715	6751	—	—	—	7268	—	—	4788	—	6140
82	2772	5414	—	—	—	5096	—	2965	6329	—	6318	2764	8732	—	2737	—	7671	2735	3019	3667	3165	4711
83	2918	4431	—	—	—	4724	—	3008	6093	—	6463	3164	8066	—	2552	—	7803	3098	3794	4974	3735	6211
84	4147	6308	—	—	—	5138	—	3496	7134	—	7196	4130	7451	—	5020	—	8933	3485	4244	4910	4139	6243
85	3136	4632	—	—	—	4725	—	3343	5955	—	6550	3112	7482	—	3723	—	8268	3001	3005	4203	3383	5179
86	2008	2296	—	—	—	2935	—	2218	3235	—	4666	2162	5111	—	2011	—	5443	2282	2254	2616	2447	3702
87	3286	4049	—	—	—	5330	—	2929	4942	—	6569	3585	6180	—	4093	—	7631	3170	3870	4622	4097	5632
88	2144	3119	—	—	—	3417	—	2315	3976	—	5034	2064	5792	—	3217	—	5645	2195	2328	2888	2498	3864
89	2402	4521	—	—	—	3579	—	2463	6366	—	5858	2352	7649	—	3374	—	6606	1971	3458	4224	2656	4892
1890	2474	3641	—	—	—	4736	—	2585	4820	—	5466	2563	5878	—	4162	—	6624	3049	2801	5020	3239	5254
91	2602	4305	—	—	—	4588	—	2884	5601	—	6821	2692	7509	—	3823	—	6876	3087	2951	5740	3296	5825
92	2066	3211	—	—	—	3072	—	2112	4160	—	4135	2438	5384	—	2979	—	4107	2579	2021	4188	2313	4255
93	1345	1375	—	—	—	1592	—	1554	1883	—	1871	1751	2400	—	2331	—	2272	1959	1756	1992	2508	2743
94	2319	7249	—	—	—	6194	—	2266	8352	—	6719	2547	8743	—	8767	—	6270	3712	3154	7155	3484	5722
95	1366	1959	—	—	—	2146	—	1480	2284	—	2800	1679	2394	—	2506	—	2888	1955	1809	2667	1965	3390
96	1266	3045	—	—	—	3154	—	1363	4137	—	3565	1468	4548	—	4169	—	3979	1881	1930	3716	1968	3381
97	1415	1916	—	—	—	2588	—	1729	3508	—	3479	1418	3979	—	2915	—	3958	1658	1671	3977	1629	3139
98	2212	4225	—	4794	—	3915	—	2048	6983	—	5627	2527	8150	—	6437	—	5800	3199	3160	6647	3751	6561
99	1782	2946	—	4181	—	4995	—	1312	4468	—	5374	1442	5161	—	3190	—	7362	1774	2334	4875	2131	4083
1900	1350	1968	—	2564	—	2627	—	1123	3577	—	3644	1363	4219	—	2526	—	4612	1196	1774	3780	1412	2669
01	1351	166	—	823	—	2274	—	1236	1769	—	2480	1206	732	—	1337	—	3585	1464	1503	2996	1727	3949
02	2247	965	—	2290	—	4425	—	1901	4970	—	6339	2941	4683	—	3750	—	5817	3851	3369	6486	4062	6648
03	1712	1224	—	2813	—	3067	—	1529	3544	—	3749	1739	3338	—	2539	—	6388	2599	1480	4914	1664	4474
04	774	32	—	517	—	823	—	1170	661	—	2058	1184	827	—	38	—	2799	780	904	2704	1513	2250

05	1099	—	—	1701	1497	2374	—	1709	3748	3358	3992	2454	1620	2200	1696	2845	4821	2565	1933	3586	2825	5779
06	1522	703	3049	3941	4140	4042	—	1244	4499	4245	3471	1707	4192	4854	1593	3071	6311	1364	2344	5472	2089	2956
07	1678	564	1927	4030	3752	5362	3297	1667	5086	5706	4357	2088	3143	6025	2351	3843	5411	2229	4478	3688	3492	4427
08	1920	193	700	2774	2662	3756	3354	1814	1728	2765	4002	1839	641	2541	702	1976	4290	2452	3788	2420	3628	4014
09	1392	177	455	2563	2382	3148	2912	1258	3286	3970	2663	1386	686	3252	674	3041	2830	1486	2517	3753	2187	5423
1910	2255	100	2131	3593	3822	4170	3530	2220	2846	3713	4320	2360	1311	3869	892	2040	4978	2226	3855	4117	3635	3065
11	1215	338	2780	1966	1589	3376	3175	1129	1273	2175	2660	1397	456	1816	311	959	2417	1500	2737	2892	3238	3331
12	1479	548	2834	2738	2048	2150	1970	1160	3379	3477	1998	1286	1787	3761	1039	3187	2311	1010	2506	2602	2252	2417
13	1957	113	1832	2098	2244	3437	2632	2049	2057	3257	3654	2077	1100	2322	146	1816	3969	2476	2953	3304	2967	4336
14	633	—	1622	1041	897	1398	1195	613	1139	2608	1117	860	85	1454	65	675	1537	519	1583	1877	1042	2526
15	2030	161	2300	1850	2298	2938	2600	2046	2898	2870	2889	1949	438	1889	1721	3189	2946	2287	2725	3239	2674	3789
16	982	247	1255	1130	1191	2280	1669	908	1418	2096	2494	1159	—	1815	—	883	2298	1317	1720	2487	1742	2888
17	1194	311	1400	1302	2072	2719	2522	1755	1366	2012	3744	1530	277	675	613	1011	3496	2016	2914	1923	3258	3674
18	2146	113	2689	2696	2267	3262	2805	2422	3254	4145	3473	2243	1677	3452	1184	2372	3605	1590	2309	4427	1958	4391
19	1274	242	1395	988	1758	2269	2174	1708	1307	1796	2204	1275	558	1766	934	1446	2714	1705	2208	1908	1945	3604
1920	1536	256	1196	1871	1568	3105	2841	1653	2315	2655	2972	1047	1170	2296	546	2599	2570	1117	2865	2562	2757	3006
21	849	128	987	1228	1738	2653	2314	1339	1190	2650	3156	1477	1128	1817	821	1841	3794	2076	1577	1993	2162	5357
22	1451	276	1492	1664	1474	2221	2082	1492	2492	2918	2365	1224	1188	1766	748	1842	1976	1532	2902	2311	2384	2185
23	892	—	1329	378	760	1936	1738	1615	342	1229	2059	1033	618	780	142	1148	1759	649	2132	1689	1827	2357
24	583	—	1210	746	1417	2920	2858	862	1116	1477	3189	587	—	2273	—	1212	3290	1671	3680	2255	4527	4659
25	280	—	—	219	112	2050	634	312	—	494	495	244	424	686	—	—	384	297	322	554	400	877
26	1483	668	1479	2598	1741	3397	2275	1460	3463	3470	2513	1553	512	2326	250	346	3642	1798	3006	1086	2440	1867

TABLE 124.—NITROGEN CONTENT OF BARLEY GRAIN DRIED AT 100° C.

Year.	Plot 1.	Plot 2a.	Plot 2aa.	Plot 2b.	Plot 3a.	Plot 3b.	Plot 4a.	Plot 4b.	Plot 5a.	Plot 5b.	Plot 6.	Plot 7.	Plot 9a.	Plot 9b.	Plot 10a.	Plot 10b.	Plot 11a.	Plot 11b.
1883	—	1·76	—	—	—	—	—	—	—	—	1·56	—	—	—	—	—	—	—
84	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2·23
85	2·15	1·69	—	—	2·11	—	1·74	—	1·80	—	1·73	1·98	2·14	2·09	—	1·80	—	1·87
86	1·93	2·00	—	—	1·94	—	—	—	1·75	—	—	1·89	1·83	2·03	—	2·16	—	2·17
87	1·92	—	—	—	2·40	—	1·61	—	1·87	—	1·81	1·96	2·23	1·81	—	1·76	—	1·75
88	1·75	—	—	—	1·85	—	1·63	—	1·87	—	1·81	1·81	2·05	1·82	—	1·73	—	1·79
89	1·64	—	—	—	—	—	1·58	—	1·57	—	1·67	1·88	1·92	1·69	—	1·62	—	1·71
1890	1·76	2·10	—	—	2·05	—	1·63	—	1·96	—	1·85	1·73	2·19	1·65	—	2·18	—	1·73
91	1·87	2·21	—	—	1·71	—	2·01	—	1·97	—	1·93	1·89	2·35	1·81	—	2·06	—	1·89
92	1·73	2·01	—	—	1·84	—	1·46	—	1·93	—	1·66	1·67	2·00	1·55	—	1·76	—	1·67
93	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
94	1·64	2·00	—	—	1·87	—	1·39	—	1·93	—	1·73	1·62	2·14	1·74	—	1·82	—	1·72
95	1·97	—	—	—	2·44	—	2·24	—	2·31	—	2·38	2·01	—	—	—	2·06	—	2·03
96	—	—	—	—	—	—	—	—	—	—	—	2·15	—	—	—	—	—	—
97	1·87	2·09	—	—	—	—	1·70	—	—	—	1·90	1·88	2·32	1·72	—	2·04	—	1·74
98	1·74	1·95	—	2·26	1·88	—	—	—	2·31	2·01	1·56	1·57	2·14	—	—	1·94	—	1·75
99	1·83	2·31	—	2·18	2·07	—	1·66	—	2·23	1·94	1·87	1·82	2·20	1·71	—	2·00	—	1·71
1900	2·15	2·46	—	2·33	2·28	—	1·82	—	2·29	1·96	1·99	—	2·33	1·90	—	2·19	—	1·95
01	2·09	2·45	—	2·39	2·59	—	1·99	—	2·34	2·32	2·36	1·97	2·70	2·02	—	2·42	—	2·06
02	1·67	2·30	—	2·31	1·93	—	1·45	—	2·00	1·66	1·63	1·58	1·92	1·58	—	1·90	—	1·58
03	1·91	1·99	—	1·93	1·72	—	1·70	—	1·64	1·75	1·60	1·68	1·66	1·54	—	1·69	—	1·62
04	1·76	1·86	—	1·94	2·09	—	1·63	—	1·76	1·80	1·83	1·73	2·14	1·75	—	2·04	—	1·72

05	1·93	2·18	—	2·24	2·29	—	1·74	—	2·00	1·98	2·10	1·87	2·38	2·07	—	2·30	—	2·08
06	1·73	1·97	—	1·97	1·97	—	1·61	—	1·90	1·75	1·72	1·73	2·13	1·59	—	1·89	—	1·70
07	1·57	—	1·74	1·71	1·75	1·55	1·46	—	1·55	1·42	1·52	1·53	1·54	1·52	1·41	1·64	1·51	1·58
08	1·94	—	2·18	1·94	2·03	1·83	1·94	—	2·03	1·90	1·64	1·99	1·86	1·88	1·76	1·93	1·75	1·87
09	1·74	1·69	—	1·73	1·94	1·76	1·71	—	1·86	1·67	1·68	1·77	1·78	1·57	1·64	1·78	1·77	1·79
1910	1·69	—	1·83	1·78	1·66	1·55	1·57	—	1·59	1·56	1·49	1·63	1·47	1·48	1·58	1·52	1·56	1·53
11	2·31	—	2·34	2·35	2·54	2·70	2·06	—	—	2·08	2·51	2·49	2·46	2·25	2·52	2·57	2·52	2·08
12	1·77	1·83	—	1·96	1·88	1·82	1·75	—	1·96	1·94	1·78	1·81	1·78	1·71	1·84	1·79	1·80	1·83
13	1·92	2·19	—	1·87	2·14	2·06	1·82	—	2·41	1·70	1·89	1·92	1·72	1·81	1·87	2·02	1·92	1·64
14	1·80	1·96	—	2·07	2·35	2·27	1·76	—	—	2·08	2·00	1·87	2·17	1·90	1·94	2·06	1·93	1·90
15	1·78	1·94	—	1·97	2·05	2·04	1·83	1·76	2·04	1·93	2·00	1·76	2·04	1·68	2·12	2·08	2·02	1·74
16	1·60	1·71	—	1·73	1·88	1·67	1·55	1·57	1·57	1·54	1·68	1·71	1·76	1·63	1·63	1·67	1·70	1·56
17	1·83	2·11	—	2·07	2·18	2·00	1·72	1·66	2·01	1·83	1·73	1·79	1·90	1·67	1·85	2·04	1·83	1·76
18	1·75	1·62	—	1·74	1·71	1·63	1·63	1·54	1·58	1·54	1·53	1·65	1·67	1·51	1·66	1·66	1·61	1·69
19	1·77	2·08	—	2·01	2·13	2·12	1·80	1·70	1·83	1·88	1·84	1·82	2·01	1·86	1·96	2·03	1·89	1·85
1920	1·68	1·70	—	1·80	1·82	1·62	1·58	1·58	1·72	1·67	1·59	1·62	1·63	1·70	1·62	1·68	1·69	1·87
21	2·25	2·34	—	2·40	2·44	2·50	2·38	2·30	2·38	2·31	2·44	2·25	2·51	2·37	2·42	2·46	2·55	2·61
22	1·55	1·73	—	1·75	1·82	1·78	1·61	1·60	1·56	1·65	1·65	1·64	1·80	1·70	1·74	1·68	—	—
23	1·90	—	2·06	2·08	2·12	2·15	1·88	1·74	2·11	1·91	2·07	2·08	2·04	2·29	2·13	2·13	2·18	1·92
24	1·43	—	1·49	1·44	—	1·51	—	1·45	—	1·37	1·44	1·40	1·86	—	1·42	1·44	1·50	1·52
25	1·92	—	2·17	2·31	2·35	2·18	1·94	1·91	—	2·14	2·29	2·04	2·50	2·26	2·18	1·96	2·35	2·34
26	1·79	1·72	—	1·74	1·93	1·96	1·79	1·90	1·73	1·78	1·96	1·80	1·95	1·95	1·83	1·86	1·89	1·81

TABLE 125.—NITROGEN CONTENT OF WHEAT GRAIN DRIED AT 100° C.

Year.	Plot 1.	Plot 7.	Plot 3.	Plot 4.	Plot 6.	Plot 11b.
1883	—	—	—	—	2·12	—
84	—	2·07	—	—	—	2·54
85	—	2·04	2·42	1·99	2·05	2·14
86	2·31	—	2·42	2·38	2·36	2·19
87	1·94	—	2·12	1·94	2·16	1·97
88	—	—	2·38	2·38	2·35	2·46
89	—	2·03	1·95	1·95	1·88	—
1890	2·13	—	2·06	2·42	1·95	2·12
91	—	1·83	1·95	1·88	1·78	1·98
92	1·81	—	1·85	1·81	1·75	1·73
95	2·01	—	2·14	—	2·39	2·32
96	2·04	—	2·35	2·00	2·49	2·10
97	2·09	—	2·32	2·19	2·20	2·25
98	1·78	—	2·21	1·96	2·10	1·96
99	—	2·27	2·04	2·28	1·98	2·17
1900	2·12	—	2·50	2·26	2·26	2·16
01	2·18	—	2·56	2·34	2·86	2·33
02	1·85	—	2·08	1·91	—	—
03	1·81	—	2·02	1·92	1·99	1·92
04	1·94	—	2·20	2·04	2·18	2·14
05	1·97	—	2·36	2·02	2·32	2·15
06	1·92	—	2·13	2·03	2·08	2·09
			Plot 3b.			
07	1·69	—	1·79	1·76	1·68	1·90
08	1·76	—	1·75	1·83	1·59	1·83
09	1·82	—	1·97	1·84	1·82	2·02
1910	1·77	—	1·75	1·78	1·66	1·94
11	2·13	—	2·11	2·14	2·17	2·24
12	1·95	—	2·16	1·97	2·03	2·05
13	1·89	—	2·01	1·87	1·84	1·89
14	2·06	—	2·11	2·00	2·17	2·04
15	1·94	—	2·39	1·94	2·47	2·07
16	1·94	—	2·22	2·06	2·08	2·06
17	2·14	—	1·98	2·24	1·95	2·00
18	1·74	—	1·77	1·80	1·78	1·80
19	2·05	—	2·38	2·01	2·24	2·19
1920	1·77	—	1·77	1·80	—	1·80
21	1·88	—	1·90	1·91	1·73	1·92
22	1·80	—	1·87	1·88	1·89	1·91
23	1·80	—	—	1·85	2·02	2·08
24	—	1·53	1·50	—	1·50	1·67
25	—	2·11	1·79	1·86	1·93	2·18
26	1·57	—	1·69	—	1·85	1·76

TABLE 126.—RATIO OF FIVE-YEAR MEANS OF YIELDS OF GRAIN TO TOTAL PRODUCE.

Plots.	1877–1881.	1882–1886.	1887–1891.	1892–1896.	1897–1901.	1902–1906.	1907–1911.	1912–1916.	1917–1921.	1922–1926.
					Barley.					
1	43	46	45	42	44	46	47	38	38	32
2	43	44	47	45	42	14	—	44	40	48
3a	41	44	44	44	45	44	38	33	39	34
3b	—	—	—	—	—	—	41	37	40	30
4	43	45	49	47	46	49	37	42	40	37
5	42	46	47	45	44	32	41	26	39	36
6	41	43	44	44	45	43	40	39	43	37
7	43	45	47	45	47	47	38	39	42	29
8a with nitrogen	42	43	43	44	47	39	42	41	39	41
8b no nitrogen	—	46	48	44	46	46	44	30	40	37
9a with nitrogen	39	40	40	42	46	42	39	36	43	37
9b no nitrogen	—	48	49	44	48	46	46	40	43	36
10a	—	—	—	45	46	47	38	39	44	34
10b	42	—	—	45	44	45	42	40	39	30
11a	—	46	46	45	45	47	39	38	43	38
11b	45	46	47	45	45	46	45	40	43	39
					Wheat.					
1	33	33	34	36	36	34	38	38	38	30
2	31	36	36	42	42	32	33	35	40	30
3a	31	33	33	34	35	33	36	33	39	31
3b	—	—	—	—	—	—	36	35	38	33
4	31	35	33	36	35	35	37	36	38	27
5	31	36	35	41	42	41	41	39	41	25
6	30	35	35	39	39	36	36	36	40	31
7	32	35	33	39	38	39	39	40	41	30
8a with nitrogen	30	35	34	41	42	39	33	31	36	30
8b no nitrogen	—	37	36	39	41	35	34	38	39	34
9a with nitrogen	29	31	30	36	37	35	36	32	40	26
9b no nitrogen	—	34	34	40	38	37	37	36	42	26
10a	—	35	35	40	40	38	37	38	40	29
10b	33	34	35	39	39	36	39	40	40	33
11a	—	34	36	40	41	38	36	35	40	27
11b	32	35	36	38	37	34	35	34	38	26

TABLE 127.—SLOW CHANGES IN YIELD. (BUSHELS PER ACRE), 1877–1906.

Plots.	1.	2a.	3a.	4a.	5a	6.	7.	8 (S.A.)	9 (N.S.).	11b.
					Barley.					
Mean Yield.	18·49	23·67	31·31	20·40	28·42	40·79	18·25	35·17	47·14	38·45
x_2'	−33·22	−80·31	−33·34	−14·79	−79·57	−22·33	−20·15	−84·36	−21·09	− 2·10
x_3'	+ 3·63	−20·17	− 7·48	− 7·12	−28·59	−11·14	− 2·82	−26·48	− 1·52	− 9·16
x_4'	+14·47	+22·96	+22·85	+10·07	+22·18	+22·11	+12·52	+21·33	+26·19	+15·86
x_5'	− 7·94	+ 0·15	−10·01	+ 0·41	+ 4·12	− 5·22	− 2·91	+ 4·17	− 3·09	− 5·41
x_6'	+ 3·83	− 1·57	+13·56	+ 3·52	− 2·77	+ 8·67	+ 4·64	−11·77	− 2·07	+17·54
Standard Deviation	6·4	6·3	9·3	7·8	9·1	9·4	6·0	9·9	10·0	9·7
					Wheat.					
Mean Yield.	12·72	18·79	21·47	12·87	28·28	28·72	14·22	32·59	32·37	26·18
x_2'	−19·42	−38·42	−15·85	−20·68	−15·12	−19·62	−13·56	−36·65	−17·84	− 4·95
x_3'	− 2·13	−22·59	−10·98	− 2·33	−11·16	−15·84	− 2·30	−24·26	− 1·98	−15·65
x_4'	+ 4·17	+ 0·84	+ 8·08	+ 8·26	+ 9·03	+13·63	+ 9·68	+ 3·97	+16·48	+13·18
x_5'	+ 0·10	+ 3·15	+ 0·24	− 2·19	− 0·47	− 7·86	+ 0·08	+ 4·65	− 7·27	− 8·89
x_6'	− 5·88	+ 0·58	− 4·36	− 3·38	+ 9·54	− 6·14	− 5·89	+ 6·65	− 6·90	− 6·63
Standard Deviation	4·2	9·6	9·0	3·8	10·9	8·4	4·8	11·8	8·2	7·9

For definitions of x_2' . . . x_6' see Fisher, *Phil. Trans.*, B, 213, 1924, p. 115.

TABLE 128.—NO. OF HOURS OF BRIGHT SUNSHINE PER MONTH AT WOBURN.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1881	62	38	131	170	222	183	224	137	100	123	74	54
82	40	47	143	157	246	135	184	154	133	75	72	38
83	56	78	138	137	171	181	136	177	122	83	88	24
84	29	60	97	102	215	147	133	225	133	87	41	14
85	16	56	122	148	175	212	238	149	131	88	47	55
86	55	46	79	142	156	193	207	189	145	75	56	65
87	56	91	116	159	122	235	268	223	100	98	60	38
88	50	40	73	93	217	110	97	154	133	139	32	53
89	39	49	86	90	131	195	154	172	116	83	56	46
1890	57	71	110	137	215	119	141	190	166	136	65	13
91	83	105	97	107	154	154	121	144	154	125	40	58
92	51	56	107	219	187	206	146	196	126	87	35	56
93	47	57	198	254	206	207	167	221	163	129	52	65
94	60	89	174	150	155	142	141	132	89	49	70	44
95	38	91	95	144	247	197	173	211	217	84	48	34
96	42	80	87	148	208	194	208	134	82	92	89	35
97	40	42	127	127	236	152	232	215	133	99	38	49
98	25	78	101	155	139	156	196	189	205	86	61	51
99	67	99	149	114	211	227	233	245	164	120	53	38
1900	49	55	89	173	169	164	267	174	158	114	43	35
01	54	41	73	199	237	225	211	223	130	102	73	53
02	56	64	94	138	141	162	174	130	154	68	43	34
03	55	75	125	127	158	149	138	170	143	74	45	23
04	36	42	83	133	137	186	231	210	163	97	68	35
05	74	63	123	98	200	149	229	164	113	88	64	44
06	65	73	106	209	128	216	241	236	194	94	38	48
07	73	86	200	126	155	150	153	168	172	103	57	43
08	59	67	102	126	179	237	193	184	141	134	71	30
09	67	94	73	229	276	97	178	209	93	88	92	58
1910	67	84	161	100	182	176	116	144	103	65	76	19
11	60	72	79	150	192	205	297	223	204	89	56	50
12	46	46	86	231	148	185	128	101	95	126	42	30
13	47	62	109	113	200	185	95	143	115	115	87	37
14	43	83	93	233	166	232	152	184	214	77	65	42
15	38	85	89	163	209	242	166	170	166	68	78	30
16	53	73	60	198	174	139	163	172	95	88	74	26
17	—	—	—	—	—	—	—	—	—	—	—	—
18	198	71	138	30	205	68	191	160	139	60	74	28
19	34	39	93	96	236	202	104	215	157	129	46	28
1920	47	76	134	70	220	216	137	129	99	109	54	27
21	37	71	121	183	221	214	250	163	174	139	55	42
22	46	101	107	138	267	217	148	130	95	139	55	43
23	53	58	69	111	152	116	56	73	174	90	87	23
24	52	43	152	146	179	172	210	147	118	27	33	43
25	45	68	82	113	187	168	145	133	114	84	87	42
26	39	38	120	111	136	182	162	201	141	104	54	44
27	54	56	131	181	207	183	132	177	110	91	59	21
28	68	97	88	128	161	224	249	177	200	117	68	44
29	30	56	168	144	243	212	223	212	201	113	70	51
1930	54	49	115	104	145	211	176	206	119	126	70	19
31	53	59	146	106	160	173	137	134	106	101	62	35
32	42	50	123	117	106	178	116	172	109	98	43	50
33	64	94	185	150	164	221	255	246	172	87	49	43

TABLE 129.—MONTHLY MEANS OF MINIMUM DAILY TEMPERATURE AT WOBURN IN DEGREES C.

Minimum.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1880	−2·2	2·1	1·6	3·8	5·1	8·9	11·6	12·6	10·8	4·0	1·9	2·4
81	−4·6	0·2	1·2	2·2	5·6	8·8	12·0	9·9	8·9	3·6	5·6	0·9
82	2·0	2·0	2·6	3·7	6·1	8·6	10·7	10·5	7·4	6·2	2·5	0·3
83	1·8	2·3	−2·2	2·9	5·7	9·1	10·1	11·0	9·4	6·4	2·3	1·6
84	3·6	1·8	2·2	2·0	5·8	8·6	11·3	11·4	10·2	5·2	2·0	1·4
85	−0·4	2·6	0·0	3·1	4·1	8·7	10·9	9·3	7·8	3·6	2·3	0·1
86	−1·5	−2·3	0·2	2·7	5·6	8·3	11·0	11·1	9·3	7·7	3·3	−1·6
87	−2·1	−0·6	−1·1	1·1	4·8	8·9	11·1	9·7	7·2	2·9	1·1	−0·7
88	−0·2	−1·5	−0·3	2·0	5·2	8·7	9·8	9·8	8·7	3·2	4·9	1·5
89	−0·9	−1·1	0·2	2·9	7·9	9·9	10·4	10·4	8·5	4·8	3·4	−0·6
1890	2·1	−0·3	1·7	2·4	5·7	9·0	10·2	9·8	9·6	5·8	2·2	−4·8
91	−2·9	−0·6	0·6	1·2	4·7	9·8	10·3	10·2	9·4	5·8	2·5	0·3
92	−1·5	−0·1	−1·7	1·1	6·2	7·8	9·3	10·6	8·3	3·4	3·2	−1·4
93	−1·3	1·4	1·5	2·9	6·8	9·1	11·4	12·4	8·1	6·1	1·2	0·6
94	−0·4	1·1	1·6	4·2	4·6	9·0	10·9	10·3	7·8	6·1	4·3	1·8
95	−2·9	−6·3	1·4	3·5	6·0	8·1	10·8	10·9	9·0	3·5	3·9	0·4
96	1·4	0·2	2·8	4·1	5·6	10·7	10·8	9·7	9·7	3·7	0·8	0·6
97	−1·3	2·6	3·1	2·8	4·8	10·0	10·9	11·3	7·9	5·3	3·2	1·2
98	2·9	0·8	0·1	2·7	5·6	8·6	10·2	11·5	9·7	7·6	3·4	3·5
99	1·6	0·8	−0·5	3·9	4·9	9·5	12·3	11·8	9·0	4·2	4·3	−1·1
1900	0·8	−0·8	−0·2	2·9	5·3	9·6	12·6	11·1	8·6	5·7	4·0	3·7
01	0·6	−1·3	−0·2	2·7	4·3	7·9	10·9	10·4	8·7	4·8	0·5	0·0
02	1·5	−2·1	2·6	2·2	3·7	8·1	9·6	10·0	7·2	5·5	3·3	2·1
03	1·0	3·3	3·0	1·4	5·8	7·2	10·6	10·0	8·9	7·8	2·5	0·8
04	0·6	0·1	0·4	4·3	6·3	7·7	11·6	9·7	6·4	4·7	1·1	0·2
05	−0·5	2·1	2·8	3·2	4·5	9·9	12·1	10·1	8·1	2·6	1·2	1·6
06	2·7	−0·2	0·9	0·3	6·1	7·5	10·2	11·4	7·9	7·7	4·2	−0·8
07	0·2	−0·7	0·3	2·9	6·1	8·9	8·9	10·1	7·2	5·4	2·7	1·9
08	−1·5	1·9	0·3	1·7	8·2	8·7	10·4	9·5	8·4	6·9	3·7	0·8
09	0·3	−2·1	0·5	2·5	3·8	7·7	10·5	10·2	7·9	7·5	1·3	1·2
1910	0·7	2·1	0·4	3·0	6·1	9·9	10·2	11·1	7·7	7·3	−0·5	3·8
11	0·6	1·4	1·6	3·3	6·8	9·0	11·3	12·4	7·8	5·2	2·9	3·8
12	0·7	2·8	4·2	2·0	7·1	9·2	11·4	9·4	6·1	2·6	3·1	4·1
13	2·0	0·9	2·5	3·4	6·8	8·6	9·6	9·3	9·3	6·6	4·5	1·9
14	0·7	3·1	2·3	3·1	4·5	7·9	11·1	10·4	6·6	6·2	3·0	1·9
15	1·6	0·9	0·8	1·9	4·9	7·6	10·1	10·5	7·6	4·6	−0·8	2·6
16	4·0	1·0	0·1	3·0	6·6	7·4	10·1	11·1	7·8	7·1	3·1	−1·5
17	−0·4	−2·7	−1·2	0·3	6·7	9·7	11·0	12·2	10·1	3·6	4·6	−1·8
18	0·5	2·1	0·7	2·7	7·0	6·7	10·4	11·4	9·1	5·8	1·9	4·7
19	−0·1	−3·8	0·6	2·3	6·8	9·1	9·4	10·9	7·7	1·7	0·5	2·4
1920	1·4	1·4	2·7	5·2	6·9	8·4	10·1	8·3	8·4	5·1	1·9	1·3
21	4·2	0·6	3·2	2·8	5·4	7·4	10·9	11·5	8·3	7·5	0·3	2·8
22	0·6	0·8	−0·4	1·1	7·3	8·0	9·7	9·3	7·7	3·8	1·1	2·8
23	1·6	2·9	2·6	2·8	5·6	8·3	12·6	10·3	7·4	6·4	−0·8	−0·4
24	1·6	−0·3	−1·8	2·3	7·3	9·5	9·9	10·0	10·1	6·2	3·4	3·4
25	1·8	1·8	0·4	2·5	7·1	8·4	11·6	11·3	7·4	6·4	0·6	−0·2
26	0·5	4·1	1·9	4·2	5·7	8·2	11·9	11·3	10·4	3·7	2·8	0·7
27	1·0	0·3	3·8	3·7	5·6	7·6	11·3	11·4	8·7	5·9	2·5	−1·1
28	1·4	1·2	2·0	3·2	4·7	7·7	10·4	10·6	6·2	5·8	3·4	−0·5
29	−1·8	−4·4	−1·6	1·3	5·6	7·9	10·3	10·7	9·8	5·9	2·9	2·7
1930	−2·3	−0·2	1·2	4·2	6·3	10·1	10·8	11·4	9·8	6·8	2·1	1·2
31	−0·1	0·5	−0·9	4·2	6·4	10·1	11·1	9·9	7·2	3·2	4·4	2·2
32	2·6	−1·1	−0·9	3·0	6·1	8·2	11·9	12·2	8·3	4·8	3·3	1·9
33	1·9	0·1	1·6	3·4	6·6	8·7	12·4	11·4	9·7	6·4	2·5	−1·9

TABLE 130.—MONTHLY MEANS OF MAXIMUM DAILY TEMPERATURE AT WOBURN IN DEGREES C.

Maximum.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1880	3·2	9·1	11·2	12·1	15·2	18·2	20·3	20·8	20·1	11·1	9·3	8·1
81	1·4	4·9	9·8	12·3	17·7	19·4	23·3	18·9	17·1	10·5	11·9	5·9
82	6·9	8·2	12·0	12·8	17·0	17·4	20·1	19·5	16·9	13·0	8·2	5·9
83	6·6	8·8	5·8	13·2	15·9	19·5	19·4	21·4	17·5	12·9	9·3	6·0
84	8·2	8·1	10·6	11·1	17·4	19·7	21·7	23·4	19·1	12·6	7·4	5·9
85	3·9	8·7	8·4	12·3	13·6	19·4	22·7	18·6	16·6	10·2	7·4	5·4
86	3·6	2·4	7·2	12·2	15·2	17·9	21·6	20·9	18·2	14·1	8·5	4·2
87	3·8	6·6	6·8	10·9	13·3	20·9	24·7	22·2	15·5	10·4	6·7	4·7
88	5·1	3·1	5·8	9·7	15·8	18·4	17·9	19·1	16·8	12·2	9·6	6·8
89	4·3	4·9	8·2	11·1	16·9	20·1	19·9	20·2	17·3	12·1	8·9	5·2
1890	8·1	5·6	9·8	11·4	16·8	19·2	19·3	19·3	20·7	13·9	8·6	—0·2
91	3·4	8·4	7·4	10·7	14·0	19·6	19·4	18·7	19·2	13·3	8·1	7·2
92	4·2	5·7	6·5	13·9	17·4	18·8	18·6	20·9	16·7	10·3	3·2	4·2
93	3·6	7·4	13·2	17·7	19·2	21·9	21·6	22·7	18·4	13·8	7·6	7·1
94	7·3	7·9	11·5	15·3	13·6	18·1	20·9	18·4	15·0	12·1	10·3	6·9
95	1·9	1·1	9·7	13·1	18·3	21·1	21·2	20·7	22·4	11·1	10·5	5·9
96	6·6	7·2	10·9	12·9	17·1	22·1	23·5	19·2	16·6	10·6	6·7	6·0
97	2·8	8·1	10·3	11·3	15·3	20·2	22·7	21·9	16·5	13·5	9·8	7·2
98	7·9	7·4	7·9	13·3	14·4	18·2	20·7	22·1	22·3	14·7	9·9	9·0
99	7·9	9·2	9·6	12·2	15·3	21·4	23·5	25·3	18·5	13·6	10·9	4·4
1900	6·2	5·3	6·6	13·6	15·1	19·7	24·9	20·3	19·2	13·8	9·5	9·3
01	5·5	3·8	6·9	13·8	16·8	19·7	23·3	21·6	18·5	14·8	7·8	6·2
02	8·0	4·3	10·7	13·1	13·3	18·5	19·9	19·3	17·7	12·8	9·2	6·5
03	6·7	10·3	11·1	10·5	16·1	17·3	19·8	18·6	17·5	13·7	8·9	4·9
04	6·2	5·9	7·8	13·4	15·3	18·4	23·2	20·5	17·2	13·5	8·4	6·0
05	6·0	7·7	10·7	11·4	16·1	19·1	23·1	19·7	16·7	10·6	7·9	6·7
06	7·7	5·9	8·7	13·3	15·2	19·5	22·0	23·3	19·9	14·9	10·3	5·4
07	5·7	5·9	11·7	12·2	15·4	16·9	18·3	19·3	19·5	13·7	9·8	7·2
08	4·9	8·4	7·7	10·0	17·4	19·9	21·5	19·8	17·4	16·2	10·7	6·2
09	5·8	5·9	6·6	14·9	17·0	15·6	19·3	21·4	16·0	13·8	7·7	6·7
1910	6·0	8·2	10·1	11·7	15·9	19·7	18·2	19·7	16·9	14·1	6·7	8·4
11	5·7	7·6	7·9	11·9	18·7	20·1	25·3	24·6	21·1	12·9	9·0	8·7
12	6·2	8·3	10·4	14·6	17·4	18·5	21·2	17·1	14·9	13·1	8·8	9·7
13	6·9	7·8	10·1	11·8	16·9	19·3	18·9	20·9	18·8	14·9	11·7	7·1
14	5·5	10·1	9·7	15·3	15·9	20·2	21·0	21·9	19·3	14·2	10·0	7·6
15	6·2	7·5	8·8	12·4	16·8	20·4	19·7	20·7	18·6	12·7	6·8	8·6
16	10·1	6·3	6·1	13·4	17·0	15·5	19·9	21·7	17·3	14·4	9·6	4·5
17	2·5	3·7	6·5	9·6	19·3	21·4	21·1	19·1	18·6	11·8	10·7	4·3
18	6·8	8·9	10·6	10·2	18·5	18·6	20·9	21·4	16·3	12·5	9·4	10·3
19	5·1	3·6	7·2	11·4	19·3	20·3	18·1	22·1	17·8	11·8	5·6	8·4
1920	8·4	9·5	11·6	12·1	16·1	19·4	18·8	17·8	17·9	14·7	9·2	6·9
21	10·2	8·1	11·4	13·5	17·3	19·8	25·8	20·9	20·3	18·3	7·6	9·1
22	6·9	7·7	7·9	9·9	19·2	19·7	18·4	18·4	16·6	12·4	8·8	7·8
23	8·3	8·1	9·3	11·9	14·3	16·8	23·2	20·6	17·4	13·2	6·2	6·6
24	7·1	5·3	9·0	12·2	16·2	18·9	20·9	18·6	16·9	13·7	9·6	9·8
25	9·3	9·1	7·9	11·4	16·4	20·9	21·8	19·6	15·6	14·3	7·0	5·4
26	6·6	9·4	9·9	13·6	14·3	18·2	21·4	21·3	19·1	12·1	9·4	6·5
27	7·4	6·9	10·9	12·4	17·1	17·2	19·5	19·8	16·1	14·2	9·0	3·7
28	8·2	9·6	9·9	12·3	15·4	17·9	22·7	19·7	18·4	14·2	10·6	6·1
29	3·1	2·6	11·6	10·5	16·1	17·9	21·8	20·8	22·4	13·5	10·2	8·6
1930	8·4	4·7	8·9	11·6	14·9	20·5	19·3	20·7	17·2	14·0	10·0	6·6
31	5·7	6·4	8·2	11·3	15·6	19·0	19·5	18·4	15·3	12·9	10·3	7·4
32	8·7	5·2	8·9	10·7	14·4	19·1	20·3	22·4	17·4	12·3	9·0	7·5
33	4·8	7·3	12·2	13·7	17·1	20·8	23·6	24·0	20·0	15·5	7·8	3·1

TABLE 131.—RAINFALL IN MILLIMETRES (1880–1933).

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1880	10·4	62·5	43·4	41·2	23·9	44·2	157·7	11·7	110·7	120·1	47·8	52·3	724·4
81	25·7	54·4	41·4	20·1	24·9	59·2	47·8	118·9	42·4	57·9	61·5	90·7	644·6
82	33·8	38·1	24·9	86·6	44·5	53·3	61·2	41·7	65·5	119·9	86·1	59·2	714·8
83	49·5	75·7	22·6	39·4	35·6	73·4	78·0	21·3	96·8	46·2	60·2	16·0	614·7
84	48·8	20·8	26·7	38·6	20·8	38·9	65·3	32·6	37·6	30·2	24·1	68·8	453·1
85	34·6	44·2	26·2	62·0	74·4	45·2	4·3	64·8	104·1	93·7	87·6	18·5	659·6
86	55·4	8·1	34·6	41·4	89·2	36·6	62·7	34·6	31·8	86·4	64·0	91·7	636·3
87	45·5	10·4	26·7	33·8	33·0	42·9	16·3	21·6	45·0	24·4	55·6	26·9	382·0
88	14·0	34·3	58·4	53·9	24·6	84·3	126·0	51·6	29·5	19·1	97·5	40·4	633·5
89	27·7	37·1	50·6	61·7	113·0	26·4	72·1	39·4	50·3	77·2	24·6	21·1	601·2
1890	50·0	20·8	45·2	15·5	34·0	42·9	69·3	37·3	11·7	36·3	58·9	4·6	426·7
91	38·9	0·0	23·9	33·5	72·6	44·2	54·9	110·7	30·0	161·3	49·3	88·7	707·9
92	22·4	33·8	12·7	19·6	33·0	58·4	52·1	88·1	82·6	91·4	38·4	32·0	564·4
93	45·0	49·8	6·9	4·6	34·3	25·4	111·8	60·5	24·6	64·5	46·7	31·0	505·0
94	41·4	40·4	27·9	31·2	58·2	55·4	84·8	66·6	35·8	80·3	115·6	32·3	669·8
95	42·9	5·1	35·1	31·5	10·2	7·1	108·7	82·3	20·1	63·2	98·3	40·6	545·1
96	23·1	9·1	66·0	20·6	7·6	55·4	18·0	48·8	151·4	77·0	30·0	74·7	581·7
97	56·1	59·4	77·2	40·6	34·3	48·3	10·7	102·1	52·3	22·6	25·4	70·9	599·9
98	17·3	19·1	36·6	33·8	87·1	43·4	61·2	71·1	9·1	59·7	43·4	65·3	547·1
99	55·9	48·5	17·3	55·4	62·2	23·4	39·9	24·1	43·9	59·2	58·9	30·0	518·7
1900	86·1	106·7	22·4	23·6	40·9	57·2	54·1	100·6	9·7	57·9	52·6	71·9	683·5
01	14·5	25·4	61·0	55·6	34·6	29·2	66·3	40·4	40·6	48·0	16·3	77·7	509·5
02	13·7	28·2	34·0	16·5	42·9	90·7	34·8	66·3	41·7	35·6	43·9	40·4	488·7
03	62·0	17·0	72·6	36·3	82·0	126·5	97·8	87·9	54·1	159·8	50·0	29·5	875·5
04	62·0	70·9	37·9	26·7	42·2	28·5	86·9	58·9	40·4	27·9	28·5	50·3	560·8
05	15·5	18·3	62·7	46·5	18·3	92·0	23·9	67·1	43·9	28·2	53·6	20·6	490·5
06	77·7	42·9	42·4	16·5	40·9	88·4	15·2	29·7	31·8	97·8	111·3	46·2	640·8
07	26·4	25·2	21·1	55·9	88·4	42·4	47·0	46·7	16·3	95·0	46·7	93·0	604·0
08	39·4	21·6	72·6	95·0	43·4	37·3	43·9	67·3	47·8	52·6	20·8	39·9	581·7
09	16·8	10·7	61·5	37·3	38·6	98·6	73·2	58·4	57·4	102·9	18·0	66·6	639·8
1910	38·1	60·5	20·8	47·0	68·8	38·9	49·5	59·2	17·3	71·1	90·2	119·9	681·2
11	25·7	33·8	42·7	28·2	25·4	44·7	9·4	25·2	33·5	44·7	65·5	107·4	486·2
12	90·2	39·6	68·3	1·5	45·0	71·4	49·0	135·4	36·1	61·7	37·9	73·4	709·4
13	72·1	26·9	63·5	60·7	48·3	29·7	32·8	17·5	44·5	67·3	58·9	22·6	544·8
14	21·6	45·5	92·7	21·6	26·2	55·1	40·6	25·2	31·0	83·3	56·4	154·4	653·5
15	68·1	70·1	30·7	21·8	51·8	13·0	116·6	43·4	50·0	39·4	64·3	105·9	675·1
16	26·9	87·6	124·7	25·4	46·2	71·9	42·4	57·2	18·0	67·8	76·2	66·0	710·4
17	36·8	22·4	39·6	36·8	49·8	66·0	87·9	143·0	49·5	105·4	27·9	14·0	679·2
18	54·4	21·8	15·2	87·6	60·2	16·0	101·6	19·8	151·1	39·6	57·7	58·4	683·5
19	98·3	64·8	93·5	65·5	15·8	30·5	70·4	63·8	42·7	38·4	38·4	102·1	723·9
1920	49·8	14·0	49·8	86·4	56·9	41·9	93·0	32·8	51·3	26·9	35·6	45·7	583·9
21	48·5	11·9	26·4	30·7	36·6	8·6	10·9	42·7	39·6	25·4	42·4	37·3	361·2
22	58·7	51·3	39·1	98·8	25·4	35·8	102·1	97·5	63·0	19·1	27·2	60·5	678·4
23	32·5	77·2	53·3	38·1	41·4	13·5	89·7	76·7	63·0	90·9	31·8	60·2	668·3
24	57·2	12·2	17·5	75·4	147·1	59·4	77·7	57·7	80·5	102·4	65·5	92·7	845·3
25	35·8	60·7	20·8	40·4	57·4	1·5	72·6	59·2	68·1	82·8	33·0	46·5	578·9
26	65·0	67·8	4·3	65·8	60·5	62·7	50·6	30·2	47·5	67·6	86·1	10·2	618·2
27	54·6	72·9	53·1	34·3	17·8	83·1	45·5	81·0	111·0	30·5	55·1	64·0	702·8
28	93·7	36·8	39·6	28·2	36·3	60·7	65·5	70·4	17·8	93·7	59·7	61·7	664·2
29	29·5	18·3	2·5	47·0	42·7	22·1	27·9	10·7	4·3	81·0	146·8	115·8	548·6
1930	68·3	15·8	41·9	40·6	73·9	11·4	61·7	62·2	65·8	25·4	95·3	57·9	620·3
31	31·5	43·2	2·0	89·9	71·6	72·1	95·0	92·7	62·0	16·3	66·3	22·4	665·0
32	36·6	5·8	45·5	56·1	125·0	17·0	96·5	109·5	51·1	87·1	31·0	12·2	673·4
33	35·6	40·9	61·5	26·7	47·5	48·0	37·9	22·9	46·7	36·6	38·6	8·6	451·5

TABLE 132.—SIX-DAY TOTALS OF RAINFALL AT WOBURN IN HUNDREDTHS OF AN INCH.

Harvest Years.	September.					October.					November.					December.					January.						February.	
	1–6.	7–12.	13–18.	19–24.	25–30.	1–6.	7–12.	13–18.	19–24.	25–30.	31–5.	6–11.	12–17.	18–23.	24–29.	30–5.	6–11.	12–17.	18–23.	24–29.	30–4.	5–10.	11–16.	17–22.	23–28.	29–3.	4–9.	10–15.
1877	136	54	61	88	136	102	41	23	8	0	51	5	155	40	101	134	85	31	82	129	109	154	70	18	40	59	9	46
78	136	6	27	16	2	2	17	13	35	70	12	120	84	19	67	24	48	6	8	51	61	22	3	15	37	29	2	125
79	8	0	27	32	31	13	50	3	100	47	29	90	65	7	86	18	17	4	3	76	134	0	59	57	0	20	79	146
1880	3	67	71	75	86	18	0	9	39	3	2	2	0	30	32	11	2	2	4	16	22	1	37	0	0	2	47	38
81	1	111	290	34	0	109	163	3	8	190	0	21	94	33	20	3	0	28	82	60	28	2	3	39	12	63	43	115
82	26	23	4	66	48	8	48	67	100	5	44	3	13	31	[illegible]	42	47	75	202	3	34	77	2	0	1	20	1	35
83	124	3	0	83	58	10	56	114	112	178	72	125	94	41	51	11	58	20	16	77	106	12	82	39	47	113	72	113
84	59	66	0	44	241	49	6	73	34	29	98	37	30	50	12	36	24	33	0	6	19	29	4	17	98	54	12	3
85	130	20	1	41	6	1	83	14	0	12	41	31	1	13	1	77	96	47	51	4	0	56	40	3	11	73	52	20
86	80	169	25	21	41	37	121	75	76	28	192	19	16	3	171	72	21	2	0	20	59	37	56	49	75	60	4	13
87	47	62	0	0	40	37	51	184	22	15	45	177	62	1	2	25	110	152	25	107	65	69	18	27	0	32	1	0
88	114	18	51	1	64	0	31	7	11	101	68	120	0	14	11	14	38	42	9	5	13	2	5	23	6	21	12	103
89	14	64	0	5	45	12	0	0	0	39	199	33	28	33	78	16	61	1	11	85	0	38	43	19	0	18	68	67
1890	4	0	0	79	105	52	77	29	40	76	74	0	1	2	10	0	36	5	50	10	11	51	5	30	94	12	3	43
91	1	0	3	41	0	2	37	34	10	49	80	59	27	23	62	12	0	15	48	10	17	10	9	29	39	66	0	0
92	20	1	23	70	23	162	74	124	238	79	11	73	97	13	25	89	96	105	0	50	19	47	4	10	9	20	21	44
93	60	18	2	155	102	63	22	55	16	129	105	3	65	17	34	47	64	16	0	0	0	32	16	33	39	77	7	41
94	19	20	0	5	61	28	89	46	40	15	21	11	40	75	48	27	32	31	52	4	5	29	38	42	42	37	14	10
95	15	24	15	17	70	15	62	8	35	119	65	93	301	19	0	0	8	79	21	21	12	10	40	125	31	31	1	0
96	74	16	3	0	0	55	107	8	67	13	87	129	41	39	64	10	15	73	4	67	3	10	18	0	58	1	12	2
97	173	124	132	38	100	27	108	112	27	46	13	55	45	5	6	122	47	42	12	72	8	150	16	15	50	107	118	13
98	70	5	3	20	94	20	2	28	31	6	2	20	34	1	39	45	65	92	3	20	60	44	0	0	0	10	31	15
99	0	0	0	2	31	3	13	78	82	55	32	2	11	18	98	4	125	2	61	36	64	9	99	57	10	13	112	42
1900	23	1	9	30	114	48	19	0	3	164	167	63	0	0	0	41	20	9	11	42	93	95	33	39	46	77	1	93
01	34	1	2	0	23	75	13	10	6	105	67	45	40	14	50	29	44	9	40	42	128	3	8	17	7	19	31	1

TABLE 132.—SIX-DAY TOTALS OF RAINFALL AT WOBURN IN HUNDREDTHS OF AN INCH (*continued*).

Harvest Years.	September.					October.					November.					December.					January.						February.	
	1–6.	7–12.	13–18.	19–24.	25–30.	1–6.	7–12.	13–18.	19–24.	25–30.	31–5.	6–11.	12–17.	18–23.	24–29.	30–5.	6–11.	12–17.	18–23.	24–29.	30–4.	5–10.	11–16.	17–22.	23–28.	29–3.	4–9.	10–15.
1902	8	35	72	53	0	65	8	69	25	22	0	0	42	16	6	0	39	137	3	102	29	18	4	0	28	0	21	0
03	34	148	7	0	2	5	50	56	25	4	1	48	5	0	51	91	1	47	32	45	54	104	4	37	56	5	0	0
04	41	82	4	45	41	97	212	55	63	178	49	9	22	4	137	17	68	11	15	5	11	32	30	19	48	189	95	63
05	136	12	57	14	2	61	10	24	50	5	16	84	2	18	0	17	99	66	2	9	7	34	3	15	6	1	19	7
06	11	55	1	10	96	20	6	14	5	60	38	70	29	7	52	22	42	2	4	16	36	127	74	59	24	8	5	60
07	0	0	99	25	0	128	66	20	114	46	44	317	38	48	1	5	34	82	6	47	73	0	19	6	1	15	18	58
08	58	0	0	0	6	77	22	197	48	29	9	6	35	42	92	146	119	58	41	2	1	128	10	2	9	8	2	9
09	142	40	43	24	10	2	15	77	70	43	0	1	24	21	16	32	39	58	7	3	39	19	30	9	0	7	3	19
1910	24	23	51	41	78	59	62	86	57	115	39	7	38	0	2	116	39	46	33	49	6	9	56	24	54	27	20	62
11	2	9	54	0	3	17	99	50	21	51	102	35	48	6	153	221	57	187	33	27	7	62	29	1	2	0	6	9
12	0	4	23	53	52	10	12	21	84	47	34	105	71	39	11	69	97	94	129	33	19	70	83	118	66	1	39	36
13	25	9	0	0	91	64	1	9	39	141	39	16	25	10	79	19	37	37	16	177	12	28	61	73	49	105	34	23
14	141	19	5	36	0	32	102	13	49	57	36	65	97	25	3	46	25	0	11	22	6	56	9	4	8	5	25	54
15	0	26	90	6	0	0	0	118	60	145	58	19	41	16	60	83	77	149	101	201	132	28	42	47	39	28	86	53
16	50	0	3	77	67	18	2	0	37	43	64	105	117	3	12	133	73	78	65	62	68	9	10	25	7	42	30	120
17	16	4	27	11	14	84	33	48	10	56	96	75	0	155	10	0	29	4	163	53	13	92	37	22	0	4	32	3
18	264	99	516	1012	91	996	1067	1406	288	394	484	252	16	71	280	0	63	71	24	95	323	87	1095	807	103	114	252	205
19	704	1213	1382	914	1678	193	878	95	311	43	1421	193	74	28	603	217	240	512	938	240	1437	296	571	638	1075	107	304	0
1920	1142	35	193	248	63	213	170	111	599	389	484	186	374	111	150	2158	213	319	504	819	260	492	311	260	795	130	35	91
21	107	0	583	969	366	607	12	201	8	43	406	8	366	4	607	426	51	126	410	480	870	717	300	205	55	271	12	87
22	55	1059	394	107	0	229	55	24	677	8	1083	142	182	39	39	292	8	429	150	571	292	304	571	685	520	540	166	8
23	264	28	1118	350	484	343	47	20	240	252	524	516	35	0	87	67	24	617	617	617	623	822	67	162	4	83	524	575
24	146	0	1237	1075	28	370	1831	63	516	799	35	209	886	63	55	500	153	12	449	859	441	244	288	1378	284	8	99	118
25	244	547	658	677	650	713	1359	0	1299	862	449	0	1229	0	969	787	0	894	0	1158	1662	130	186	0	162	205	358	847
26	492	410	107	1449	225	39	0	507	2197	248	803	339	0	0	217	209	190	0	886	658	1170	166	107	559	457	386	1528	138

TABLE 132.—SIX-DAY TOTALS OF RAINFALL AT WOBURN IN HUNDREDTHS OF AN INCH (*continued*).

Harvest Years.	February (cont.).		March.						April.					May.				
	16–21.	22–27.	28–5.	6–11.	12–17.	18–23.	24–29.	30–4.	5–10.	11–16.	17–22.	23–28.	29–4.	5–10.	11–16.	17–22.	23–28.	29–3.
1877	60	32	48	36	2	0	88	23	109	4	30	47	3	1	64	107	13	43
78	4	3	39	6	7	1	19	48	0	91	103	20	20	156	113	72	37	61
79	65	13	32	3	12	11	26	31	58	50	41	100	1	10	34	14	106	137
1880	132	27	102	24	1	0	0	60	24	93	19	9	3	2	19	2	46	40
81	28	9	60	90	0	4	9	0	0	26	3	33	23	7	10	57	15	18
82	37	17	79	1	10	18	61	6	11	61	24	173	75	35	0	0	99	4
83	43	0	10	12	1	54	5	18	0	1	46	62	44	53	53	0	78	0
84	44	12	51	60	0	0	0	16	60	10	3	41	29	13	48	16	0	0
85	64	58	55	18	0	39	6	27	22	95	25	39	105	44	0	88	72	8
86	0	0	37	0	11	23	39	65	47	41	54	0	15	0	178	116	107	71
87	29	2	0	1	29	41	47	31	6	0	0	68	37	49	14	55	30	167
88	21	12	2	53	80	37	99	12	11	24	129	35	16	0	0	64	0	25
89	14	13	3	86	0	90	2	31	57	62	10	49	35	21	132	5	215	27
1890	31	6	11	19	17	125	32	0	12	25	18	13	0	72	31	22	0	9
91	0	0	0	74	16	17	6	7	82	12	39	0	27	21	29	128	92	26
92	17	24	16	10	13	12	27	0	0	29	7	38	45	4	21	18	42	22
93	31	88	30	0	3	0	0	0	0	0	13	0	5	0	3	108	0	16
94	82	32	20	30	64	0	0	0	1	20	28	46	33	24	81	12	40	72
95	0	11	5	31	0	16	81	33	7	0	19	100	7	0	0	22	2	3
96	19	4	28	56	36	104	32	6	3	58	9	0	5	0	6	28	6	9
97	25	0	77	16	88	69	16	25	33	14	79	5	17	9	9	0	49	67
98	15	8	26	1	5	9	98	1	13	37	2	39	52	49	37	132	25	82
99	27	1	3	14	0	12	22	11	63	55	42	29	7	15	96	57	94	0
1900	82	156	8	0	5	42	13	27	8	10	7	0	24	60	3	8	78	42
01	15	23	76	56	1	66	9	135	35	101	2	5	0	101	0	0	1	34

Harvest Years.	June.					July.					August.				
	4–9.	10–15.	16–21.	22–27.	28–3.	4–9.	10–15.	16–21.	22–27.	28–2.	3–8.	9–14.	15–20.	21–26.	27–1.
1877	11	2	0	31	58	57	56	29	118	4	23	16	98	71	101
78	29	63	44	24	1	1	0	0	37	1	86	103	28	170	108
79	76	107	55	68	126	56	61	85	34	51	136	1	121	24	77
1880	52	2	60	38	62	41	270	54	122	95	13	1	2	1	13
81	144	12	30	27	5	53	3	2	14	116	1	134	100	191	42
82	128	30	34	53	7	65	151	10	23	12	0	7	47	58	37
83	2	27	95	116	62	28	46	75	66	18	30	22	3	1	60
84	108	0	0	3	34	34	123	61	54	17	0	21	4	21	105
85	107	0	62	17	0	1	6	10	0	0	79	19	0	53	38
86	0	55	12	3	0	7	69	48	112	24	3	85	48	1	0
87	35	0	0	0	0	2	5	8	39	9	0	24	29	18	42
88	22	39	31	59	88	11	43	195	56	105	22	0	0	101	66
89	3	76	15	1	1	0	110	24	52	1	16	55	27	51	0
1890	18	24	19	58	65	53	72	141	0	23	17	56	27	31	21
91	40	0	14	76	9	101	1	3	17	84	29	29	64	176	139
92	45	20	48	80	3	28	40	122	0	11	26	12	91	50	149
93	14	0	0	68	17	14	82	116	169	61	50	62	0	34	19
94	110	21	55	0	5	16	189	31	95	2	34	75	29	119	0
95	1	11	0	2	28	17	14	220	130	37	113	150	0	51	3
96	45	49	62	47	8	11	0	26	34	5	6	64	53	61	76
97	86	13	61	0	10	0	0	23	12	0	50	118	22	51	83
98	17	0	5	83	64	0	0	8	27	115	219	6	29	2	21
99	0	0	40	8	61	18	12	0	79	0	7	0	42	0	42
1900	58	18	26	58	33	20	2	66	1	132	86	48	2	123	36
01	1	21	8	15	92	7	4	0	218	10	8	14	37	40	60

TABLE 132.—SIX-DAY TOTALS OF RAINFALL AT WOBURN IN HUNDREDTHS OF AN INCH (*continued*).

Harvest Years.	February (cont.).		March.						April.					May.					June.					July.					August.				
	16–21.	22–27.	28–5.	6–11.	12–17.	18–23.	24–29.	30–4.	5–10.	11–16.	17–22.	23–28.	29–4.	5–10.	11–16.	17–22.	23–28.	29–3.	4–9.	10–15.	16–21.	22–27.	28–3.	4–9.	10–15.	16–21.	22–27.	28–2.	3–8.	9–14.	15–20.	21–26.	27–1.
1902	4	72	58	7	48	9	18	11	19	26	11	5	39	19	17	42	33	55	84	101	88	0	64	0	32	20	45	25	85	28	80	30	38
03	8	53	48	62	12	33	108	43	8	16	0	36	146	169	27	39	0	6	35	294	166	3	0	0	11	99	206	72	37	86	68	132	20
04	36	0	34	32	4	12	31	40	17	49	0	31	34	11	15	60	46	63	0	43	3	23	19	15	3	4	224	79	8	18	31	64	110
05	10	33	10	68	133	14	18	10	55	53	30	24	34	0	5	1	0	70	165	31	76	0	86	0	51	11	11	5	80	2	19	51	112
06	59	17	30	39	31	40	49	0	0	9	20	32	19	45	5	44	42	69	0	8	53	23	205	0	37	4	1	19	27	22	40	27	0
07	22	1	0	41	26	16	0	3	20	80	58	32	65	16	174	24	78	48	38	38	6	32	41	50	56	0	42	19	77	13	66	26	2
08	27	45	33	51	23	14	140	29	67	24	15	164	132	65	60	0	4	65	15	11	66	0	0	43	66	63	1	0	10	19	0	102	134
09	0	11	19	57	35	8	59	73	0	13	59	34	47	0	4	5	131	92	107	26	23	118	28	39	65	61	24	158	2	0	97	67	5
1910	52	74	8	37	39	6	0	0	47	42	35	25	79	42	40	116	0	35	5	21	0	48	96	99	1	47	22	9	65	14	13	56	80
11	34	45	49	29	79	19	39	51	7	0	0	22	57	0	23	3	32	18	0	0	44	108	24	0	0	0	8	31	12	0	0	69	16
12	6	57	85	33	39	91	34	5	5	0	0	0	9	15	40	68	6	52	104	69	35	21	84	6	0	28	51	63	153	26	64	190	100
13	5	3	31	14	81	77	35	23	1	69	44	48	156	41	20	8	1	30	32	6	69	10	13	18	26	67	5	0	0	2	6	15	46
14	55	41	4	116	120	62	50	17	72	9	0	4	19	38	9	0	14	23	89	114	6	8	6	129	2	3	17	19	49	10	2	17	5
15	72	32	38	18	1	64	15	20	34	25	5	2	9	1	173	20	0	2	7	4	0	13	29	162	21	100	157	19	77	26	38	0	27
16	15	106	54	71	101	107	190	0	17	31	52	0	35	83	39	6	19	0	65	50	0	90	79	54	67	24	21	0	0	4	65	21	135
17	37	14	5	29	61	25	15	37	32	53	44	0	0	0	2	186	8	0	16	0	23	22	199	109	0	70	0	285	93	124	30	43	156
18	87	158	158	4	12	12	134	611	343	1449	1307	59	532	252	507	225	886	0	12	201	244	170	0	8	1197	2197	472	130	170	0	28	271	308
19	1500	650	615	1126	638	1032	221	153	221	721	12	1201	468	520	0	0	0	39	74	170	595	87	465	292	662	807	717	67	51	0	394	551	1516
1920	300	87	142	193	615	16	575	1040	689	992	500	567	244	205	186	178	977	492	20	737	441	12	807	1862	186	74	862	551	500	122	362	59	0
21	4	362	126	209	244	229	170	63	190	389	410	225	335	575	232	0	71	229	146	0	87	83	20	47	8	107	51	232	389	201	977	47	51
22	516	461	922	472	8	142	354	492	331	1126	221	1752	343	63	39	138	516	0	0	394	28	382	988	1654	331	429	1142	87	2508	374	170	284	500
23	704	1095	484	480	811	182	166	87	153	862	0	358	217	95	599	43	449	354	138	71	193	126	0	74	1846	91	441	1079	0	0	1481	780	760
24	59	166	378	0	0	205	134	12	0	1170	12	1016	1347	114	662	2426	906	1579	1245	504	103	16	126	280	0	1334	496	1044	190	0	673	457	737
25	35	1016	236	87	95	386	59	107	484	347	43	347	741	725	59	79	709	288	0	0	0	55	0	217	0	563	1767	402	1134	406	0	591	107
26	559	260	134	20	4	4	12	0	468	256	646	764	484	599	803	579	74	859	370	1118	217	201	193	737	43	229	484	311	174	571	221	59	166

TABLE 133.—RAINFALL DISTRIBUTION VALUES, 1877–1926, IN THOUSANDTHS OF AN INCH.

Harvest Year.	*a′*.	*b′*.	*c′*.	*d′*.	*e′*.	*f′*.	Harvest Year.	*a′*.	*b′*.	*c′*.	*d′*.	*e′*.	*f′*.
1877	550	−64	+35	+30	+17	−17	1902	330	+25	+23	− 3	−10	− 3
78	424	+39	+30	+12	+20	+22	03	484	+92	+26	−18	− 4	−14
79	501	+70	+ 5	+11	−28	− 4	04	459	−41	+47	+24	− 2	+15
1880	336	+45	+23	−37	−12	−27	05	335	+16	+29	−16	+15	+ 3
81	466	−34	+95	+15	+20	+11	06	323	− 4	−12	0	−11	−10
82	415	− 1	− 6	+ 2	−23	+ 7	07	413	−31	+16	− 1	−44	−27
83	495	−67	+15	+12	−31	− 5	08	433	− 1	− 5	+20	+ 2	+36
84	357	−41	+48	− 3	− 3	+ 9	09	370	+41	+42	−36	− 6	−13
85	341	− 7	−14	−16	+19	0	1910	406	−16	+19	+ 4	− 9	+15
86	459	−52	+31	−27	−18	+ 3	11	346	−65	−16	+43	−27	+ 7
87	360	−68	+ 1	+19	−21	+13	12	485	+34	+23	+71	+ 1	− 1
88	387	+35	+37	−12	+ 3	− 5	13	364	−32	−39	+11	− 1	+ 9
89	371	+12	−21	− 8	−13	+ 8	14	341	−33	− 2	−24	+ 3	− 3
1890	327	+ 2	+20	− 1	−18	+ 3	15	478	−30	−13	+53	−30	−32
91	335	+75	+39	+33	+ 4	+29	16	479	− 5	−28	+24	+13	+12
92	429	−47	+67	+43	−32	+36	17	460	+76	+58	+46	−21	− 4
93	364	−24	+63	+ 7	−25	−15	18	371	− 8	+22	−27	−16	+14
94	368	+39	+18	+ 7	−19	− 3	19	522	−61	+31	+ 1	+48	− 1
95	385	− 1	+46	+43	−36	− 9	1920	417	+13	−13	−16	−16	−19
96	317	−18	+27	+25	− 3	+14	21	243	−27	+ 5	+10	+ 7	+ 2
97	477	−87	+52	− 9	+42	− 9	22	423	+67	+12	− 2	+ 4	−19
98	327	+36	+19	− 9	−12	−10	23	382	+34	+20	+21	+26	− 5
99	314	−11	−31	+20	−15	+ 5	24	484	+30	+23	−32	−23	+25
1900	414	+ 3	+14	+34	− 4	− 2	25	445	−55	−32	+23	−16	− 1
01	340	+10	− 3	+20	− 3	+ 6	26	412	−27	− 2	−14	−14	0

For definitions of *a′* . . . *f′* see Fisher, *Phil. Trans.*, B, 213, 1924, p. 112.

TABLE 134.—SLOW CHANGES IN RAINFALL DISTRIBUTION VALUES, 1877–1926. RAINFALL IN THOUSANDTHS OF AN INCH.

	a′.	*b′*.	*c′*.	*d′*.	*e′*.	*f′*.
Mean	+401·28	− 3·34	+18·16	+ 7·46	− 6·44	+ 0·92
x_2'	+ 2·34	+ 9·93	−48·17	+ 3·45	+ 7·11	− 7·55
x_3'	+160·66	− 6·88	+ 7·59	−23·88	+17·65	− 5·44
x_4'	−118·17	−16·25	+28·11	−23·68	−22·82	+16·02
x_5'	+ 32·21	+20·26	+17·87	+ 6·42	+ 4·49	− 5·98
x_6'	− 0·64	−38·57	−28·00	−32·47	−27·69	+ 7·31
Standard Deviation	62·7	44·9	26·7	24·5	19·2	15·3

Table 135.—Partial Regression Coefficients of Yields on Rainfall Variates, 1877–1906. Yields in Bushels; Rainfall in Inches.

	Regression on					
Plot.	*a′*.	*b′*.	*c′*.	*d′*.	*e′*.	*f′*.
				Barley.		
1	−77·9187	−20·1592	+ 92·7283	− 1·1850	− 64·6331	+ 23·3948
2a	−13·5681	+12·9931	+ 58·8544	+ 87·9215	+ 16·5388	+ 5·5729
3a	−63·7060	−42·9932	+ 29·8611	+ 27·0869	− 44·3002	+ 35·4014
4	−85·3682	−29·1829	+119·0449	+ 34·6017	− 61·0222	+ 98·2830
5a	−34·0969	+25·7114	+ 69·4118	+ 83·9913	+ 12·3744	+ 9·3757
6	−57·9209	−40·3944	+ 2·8783	+ 5·6420	− 20·7086	+129·1924
7	−64·8651	−29·0090	+ 69·4287	+ 72·2998	− 25·7668	+ 21·5244
8	−29·6568	+ 8·2869	− 13·1809	+ 70·4471	+ 32·3029	+121·4207
9	− 8·0129	−29·2963	− 92·2187	+ 50·0368	+ 1·0482	+123·8021
11b	−81·3715	−46·2277	+109·8725	− 48·6084	−166·1454	+133·6409
				Wheat.		
1	−24·8456	−82·7916	+ 17·3471	+109·7685	+ 80·2860	− 88·0245
2a	− 9·0860	+11·3816	− 82·8945	+136·1033	+168·6688	−104·8409
3a	−39·7501	−15·2987	− 35·5549	+224·2952	+106·0925	−166·0498
4	−21·9674	− 5·0077	+ 49·8114	+ 76·5215	+ 67·2197	− 81·6878
5a	−20·1496	+18·0248	− 73·6072	+ 17·6297	+ 86·2005	− 89·6457
6	−33·4699	+20·7834	− 23·1581	+167·8766	+109·1769	−126·0982
7	−44·1947	−29·0625	+ 63·3566	+ 58·8261	+ 18·0378	− 63·3605
8	+13·8582	+22·7237	−114·6809	− 14·1859	+ 60·9125	+ 36·6912
9	−27·5252	−11·5648	− 60·4775	+131·2177	+100·8176	−120·4476
11b	−55·9172	+14·0651	+ 82·1400	+ 39·2386	+ 15·3982	+ 3·8477

Table 136.—Barley, 1878–1906: Regression Coefficients of Yield of Grain on March–April Rainfall (x) and Rainfall 60–90 Days after Sowing (r). Grain in Bushels; Rainfall in Inches.

Plot.	Regression on				
	$(x-\bar{x})$.	$(x-\bar{x})^2$.	$(x-\bar{x})^3$.	$(r-\bar{r})$.	$(r-\bar{r})^2$.
1	−2·7331	+0·1351	+0·6377	−0·5523	−1·4568
2	−4·4809	+1·2383	+2·2596	−1·2568	−0·3009
3	−9·1126	+2·4911	+2·5443	+1·0751	−2·3353
4	−7·3004	+1·3357	+1·7051	−0·1452	−1·4637
5	−4·7196	+1·3369	+2·2929	−0·9809	−1·2768
6	−8·4030	+0·8433	+2·3643	+0·9823	−1·9544
7	−4·9389	+0·6406	+1·1967	−0·6148	−1·2083
8	−6·9903	+1·0192	+2·4925	+1·6488	−1·7280
9	−7·9641	+0·7179	+2·1535	+2·2711	−1·7406
11b	−6·1956	−0·7150	+1·1317	−0·4394	−1·8003

$(x-\bar{x})$ is the amount by which the March-April rainfall in any year differs from the average March-April rainfall (3·0 inches) in the period 1878–1906, etc.

TABLE 137.—PARTIAL REGRESSIONS COEFFICIENTS OF NITROGEN CONTENT ON RAINFALL VARIATES. NITROGEN IN PERCENTAGES; RAINFALL IN INCHES.

Plot.	Regression on					
	a′.	*b′*.	*c′*.	*d′*.	*e′*.	*f′*.
			Barley.			
1	−0·8707	−0·3914	+2·5525	+1·7801	−1·5288	−3·5111
3a	−1·5706	−1·1688	+3·8823	+1·3205	−5·5939	−0·8921
4a	−0·8840	−0·0519	+3·1647	+4·2169	−4·3265	−4·3678
5a	−1·6832	+0·3077	+3·0828	+2·3748	−3·5424	−1·9286
6	−1·5334	−0·8586	+4·3300	+1·9626	−5·1109	−3·2406
7	−1·1051	−0·4588	+3·1590	+3·6996	−4·5372	−0·1744
11b	−1·0823	+0·2725	+2·1792	+2·2410	−4·4093	−1·0062
			Wheat.			
1	−0·2847	−0·7526	+1·8621	−0·5566	−2·7907	+0·1095
3	+0·1771	−1·5607	+3·1592	−2·1706	−2·5360	+1·0374
4	−0·0268	−0·4349	+1·2814	−0·9583	−3·8549	+1·3052
6	+0·0843	−1·6293	+3·0426	−2·3360	−5·9056	+1·1293
11b	−0·0698	−0·8608	+2·5642	−0·7287	−3·9950	+0·5385

TABLE 138.—BARLEY: PARTIAL REGRESSION COEFFICIENTS OF NITROGEN CONTENT ON MAXIMUM DAILY TEMPERATURE VARIATES. NITROGEN IN PERCENTAGES; TEMPERATURES IN UNITS OF 100° F.

Plot.	Regression on					
	a′.	*b′*.	*c′*.	*d′*.	*e′*.	*f′*.
1	+0·7264	+1·1371	−0·4291	−3·4326	−1·4429	−0·1337
3a	+1·1055	+2·8462	−3·0645	−3·1093	−3·4693	+1·8535
4a	+0·8430	+0·9818	−1·6653	−2·6634	−0·4227	+0·0876
5a	+0·8172	+1·7736	−1·4237	−1·2653	−2·4678	+4·0539
6	+1·1607	+2·1887	−2·1447	−3·4695	−3·4418	+1·3132
7	+1·0584	+1·1793	−1·8199	−3·3094	−0·9500	−1·0423
11b	+0·9996	+0·7694	−1·7523	−1·3699	−0·3496	−0·0558

TABLE 139.—ROTATION ROOTS, TONS PER ACRE.

Year.	Block.		Plot 1.		Plot 2.		Plot 3.		Plot 4.		Plot 5.		Plot 6.		Plot 7.		Plot 8.	
	Mangels.	Swedes.	Mangels.	Swedes.	Mangels.	Swedes.	Mangels.	Swedes.	Mangels.	Swedes.	Mangels.	Swedes.	Mangels.	Swedes.	Mangels.	Swedes.	Mangels.	Swedes.
1877	II	—	3·85	—	2·06	—	7·22	—	3·82	—	—	—	—	—	—	—	—	—
78	IV	—	13·11	—	11·80	—	18·66	—	12·77	—	—	—	—	—	—	—	—	—
79	I	—	4·52	—	4·50	—	7·96	—	5·80	—	—	—	—	—	—	—	—	—
1880	III	—	19·53	—	18·99	—	24·52	—	20·92	—	—	—	—	—	—	—	—	—
81	II	—	22·26	—	21·71	—	24·36	—	21·68	—	—	—	—	—	—	—	—	—
82	—	IV	—	17·33	—	17·08	—	19·67	—	18·17	—	—	—	—	—	—	—	—
83	—	I	—	20·02	—	20·20	—	23·35	—	20·66	—	—	—	—	—	—	—	—
84	—	III	—	14·49	—	13·65	—	16·51	—	15·73	—	—	—	—	—	—	—	—
85	II	II	—	17·03	—	17·01	—	14·38	—	13·78	11·30	—	11·06	—	13·06	—	10·83	—
86	IV	IV	—	4·76	—	8·78	—	7·78	—	7·47	17·41	—	19·07	—	19·94	—	18·68	—
87	I	I	—	10·92	—	9·90	—	11·00	—	8·99	10·70	—	9·87	—	9·71	—	8·44	—
88	III	III	—	8·46	—	8·98	—	9·68	—	9·13	8·44	—	7·90	—	9·85	—	8·46	—
89	II	II	—	12·41	—	12·29	—	10·21	—	10·86	15·38	—	13·42	—	12·20	—	11·65	—
1890	IV	—	No	crop	—	—	—	—	—	—	10·30	—	13·63	—	14·45	—	12·54	—
91	I	I	—	10·41	—	9·80	—	8·88	—	8·55	9·10	—	8·50	—	7·67	—	7·66	—
92	III	III	—	1·35	—	1·30	—	1·36	—	1·77	10·08	—	10·82	—	11·84	—	11·34	—
93	II	II	—	6·60	—	6·44	—	8·53	—	8·71	10·14	—	11·01	—	10·70	—	8·84	—
94	IV	IV	—	8·35	—	9·97	—	10·51	—	9·73	7·69	—	8·56	—	8·03	—	8·62	—
95	I	I	—	8·48	—	8·70	—	8·24	—	7·85	9·30	—	10·66	—	10·14	—	10·18	—
96	III	III	—	11·63	—	11·48	—	13·26	—	12·72	14·21	—	12·98	—	13·68	—	12·11	—
97	II	II	—	12·80	—	14·00	—	15·43	—	14·51	5·12	—	2·75	—	2·45	—	2·23	—
1903	I	—	3·34	—	2·21	—	3·31	—	3·12	—	2·64	—	2·11	—	2·19	—	2·74	—
,,	II	—	4·29	—	2·14	—	2·64	—	3·92	—	1·94	—	1·36	—	0·85	—	1·12	—
,,	III	—	5·53	—	6·00	—	7·32	—	6·91	—	2·49	—	3·45	—	4·49	—	2·87	—
,,	IV	—	3·76	—	6·29	—	4·15	—	4·29	—	3·89	—	3·62	—	2·15	—	1·80	—
04						Rather over 12												
05	—	I	—	17·27	—	20·24	—	21·77	—	19·23	—	—	—	—	—	—	—	—
06	—	III	—	8·06	—	8·03	—	9·25	—	10·50	—	—	—	—	—	—	—	—
07	—	II	—	9·88	—	9·19	—	10·16	—	11·74	—	15·60	—	16·54	—	16·35	—	13·77
08	—	IV	—	10·97	—	10·00	—	9·90	—	10·00	—	15·45	—	15·10	—	15·30	—	15·60
09	—	I	—	7·25	—	8·92	—	10·93	—	6·56	—	10·62	—	13·14	—	15·12	—	15·59
1910	—	III	—	10·50	—	11·71	—	12·50	—	13·29	—	14·00	—	11·64	—	11·79	—	11·36

TABLE 139 (*continued*).—ROTATION ROOTS, TONS PER ACRE.

Year.	Series C.		Year.	Series D.	
	Plot 1. Corn.	Plot 2. Cake.		Plot 1. Corn.	Plot 2. Cake.
1910	—	—	1912	16·75	14·04
1914	7·04	6·95	1916	11·21	13·64
1918	About 11		1921	Small crop	
1922	Small crop		1925 [1]	1·43	1·43
1926	13·90	13·00	1929	7·25	4·10
1930	11·55	12·80	1933	7·89	9·87

[1] Only part of produce weighed.

TABLE 140.—ROTATION BARLEY. HEAD AND TAIL CORN, LB. PER ACRE.

Year.	Block.	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
1878	II	2244	2102	2788	1957	—	—	—	—
79	IV	1991	2137	2331	1726	—	—	—	—
1880	I	2175	1918	2119	1760	—	—	—	—
81	III	2526	2390	2537	2560	—	—	—	—
82	II	2644	2494	2420	2399	—	—	—	—
83	IV	2952	3273	3222	3107	—	—	—	—
84	I	2779	2782	2925	2605	—	—	—	—
85	III	3309	3132	3388	3208	—	—	—	—
86	II	2716	2338	2800	2306	2074	2147	2290	2097
87	IV	2478	2375	2720	2564	1492	1562	1840	1796
88	I	2194	1986	2392	1961	1548	1544	1705	1528
89	III	1726	1660	2080	1923	1408	1484	1694	1643
1890	II	2426	2220	2433	1992	2144	1930	2008	1814
91	IV	2481	2372	2556	2282	1280	1158	1364	1552
92	I	1958	1628	2620	1396	1416	1260	1232	1300
93	III	1594	1514	1724	1575	1311	1252	1386	1079
94	II	2542	2350	2504	2332	1666	1798	1502	1369
95	IV	2014	1774	1887	1666	763	984	1016	1042
96	I	1302	1144	1406	1108	817	801	680	722
97	III	1112	1085	1602	1368	924	928	1010	851
,,	IV	1125	1269	1375	1308	1143	1218	1175	1216
98	II	1779	1514	1709	1598	906	931	1095	1244
99	I	1574	1395	1277	1300	1383	1349	1099	1313
,,	II	1682	1896	1750	1570	1346	1706	1436	1464
,,	IV	1362	1370	1346	1172	1178	1534	1434	1394
1900	I	773	690	554	842	694	722	576	836
,,	II	880	809	678	683	712	796	750	633
,,	III	821	1052	1231	1116	1109	1204	1094	1106
,,	IV	560	602	674	582	412	296	348	512
01	I	951	835	806	774	853	772	627	780
,,	II	1174	1114	1000	1078	966	1191	970	974
,,	III	1068	1159	1232	1191	1066	1174	1147	1032
,,	IV	986	1107	1250	1244	1026	1214	1078	1000
02	I	1241	995	1176	1046	1038	1062	1020	1045
,,	II	1451	1660	1356	1326	1090	1408	1239	1204
,,	III	1368	1384	1455	1514	1757	1550	1399	1298
,,	IV	875	1144	1318	1132	912	1197	1034	1104
05	IV	2677	2203	2443	2298	—	—	—	—
06	I	3029	2628	2637	2528	—	—	—	—
07	III	3078	2885	3080	2877	—	—	—	—
08	II	2441	1657	1355	1196	2003	1927	1856	1829
09	IV	1697	2095	1766	2147	1707	2303	2119	1767
1910	I	2729	2292	2377	2661	2533	2505	2187	2347

TABLE 141.—ROTATION BARLEY. TOTAL PRODUCE, LB. PER ACRE.

Year.	Block.	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
1878	II	5471	5365	6789	5253	—	—	—	—
79	IV	5031	5418	5558	4382	—	—	—	—
1880	I	5020	4657	5185	4257	—	—	—	—
81	III	5669	5413	5793	5446	—	—	—	—
82	II	6476	6301	6484	6164	—	—	—	—
83	IV	6772	7234	7871	7843	—	—	—	—
84	I	5928	5916	7001	5760	—	—	—	—
85	III	7644	7271	8536	7663	—	—	—	—
86	II	5537	4539	5751	4346	4088	4287	4612	4099
87	IV	5690	6007	6914	6386	3336	3565	4104	4016
88	I	4894	4428	5400	4634	3572	3722	4143	4030
89	III	3892	3580	4950	4318	2973	3521	3983	3791
1890	II	5100	4562	5233	4098	4430	3940	4318	3974
91	IV	6013	5431	6122	5505	2887	2638	3004	3256
92	I	4212	3315	5042	3478	2891	2612	2614	2668
93	III	3194	2880	3342	3277	2478	2302	2562	2125
94	II	5738	5289	5694	4873	3410	3698	3209	2957
95	IV	3908	3716	3807	3627	1759	2220	2238	2326
96	I	3356	2838	3420	2901	2093	2171	1946	2008
97	III	2864	2669	4077	3230	2096	2172	2362	1915
,,	IV	2609	2943	3047	2878	2410	2656	2665	2626
98	II	4343	3688	4188	3531	2157	2251	2455	2731
99	I	3043	2819	2526	2483	2695	2732	2154	2541
,,	II	3470	3723	3411	3005	2765	3539	2884	2907
,,	IV	2728	2747	2769	2383	2412	3030	2825	2747
1900	I	1654	1423	1248	1802	1524	1488	1236	1695
,,	II	1807	1608	1390	1404	1646	1704	1550	1315
,,	III	1596	2152	2456	2287	2149	2349	2164	2279
,,	IV	1256	1368	1532	1322	1003	744	869	1133
01	I	1888	1663	1604	1484	1694	1684	1290	1556
,,	II	2320	2154	1920	1966	1848	2250	1846	1980
,,	III	2178	2364	2453	2398	2020	2279	2242	2046
,,	IV	1923	2115	2454	2377	2002	2240	2044	1916
02	I	2639	2298	2612	2354	2511	2380	2280	2292
,,	II	2919	3256	2632	2688	2324	2865	2510	2512
,,	III	2728	2734	2896	2962	3314	2924	2890	2582
,,	IV	1684	2284	2792	2486	2111	2575	2103	2298
05	IV	6200	4924	5701	5066	—	—	—	—
06	I	6987	5781	5547	5248	—	—	—	—
07	III	7667	6527	7140	6669	—	—	—	—
08	II	4979	3357	2680	2305	3933	3849	3587	3479
09	IV	5352	5712	4716	5808	4558	5899	5420	4624
1910	I	5753	4899	5121	5726	5311	5487	4685	5247

TABLE 141 (*continued*).—ROTATION BARLEY, LB. PER ACRE.

Grain.

Year.	Series C.		Year.	Series D.	
	Plot 1.	Plot 2.		Plot 1.	Plot 2.
1911	1529	1300	1913	2227	2065
1915	1568	1450	1917	1612	1480
1919	1131	1155	1918	1201	1110
1923	802	919	1922	1101	1047
1927	754	845	1926	1624	1573
1931	1483	1437	1930	1311	1770

TABLE 141 (*continued*).—TOTAL PRODUCE.

Year.	Series C.		Year.	Series D.	
	Plot 1.	Plot 2.		Plot 1.	Plot 2.
1911	3436	2825	1913	4973	4568
1915	3211	3073	1917	3611	3594
1919	2489	2515	1918	2632	2606
1923	1888	2050	1922	2273	2142
1927	2008	2256	1926	7260	7700
1931	3701	3599	1930	3047	4010

TABLE 142.—ROTATION SEEDS, CWT. PER ACRE (CLOVER-HAY OR TOTAL PRODUCE).

Year.	Block.	Crop.	Plot 1.	Plot 2.	Plot 3.	Plot 4	Block.	Crop.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
1885	—	No crop	—	—	—	—	—	No crop	—	—	—	—
86	III	Tares	56·3	54·3	55·5	50·6	III	Peas	45·8	39·4	47·4	46·5
87	II	,,	31·5	27·5	24·2	22·1	II	,,	37·4	31·6	27·2	25·1
88	IV	Clover-hay	41·4	49·6	55·8	44·8	IV	Clover-hay	31·5	31·5	24·0	16·9
89	I	,,	81·2	86·2	82·6	81·6	I	,,	77·7	76·3	82·4	77·5
1890	III	,,	57·0	60·2	66·4	74·0	III	,,	59·3	67·0	76·8	79·7
91	II	,,	69·0	73·4	74·4	78·0	II	,,	72·8	78·8	81·4	75·4
92	IV	,,	33·4	33·2	33·4	28·8	IV	,,	25·8	31·0	25·9	24·7
93	I	,,	12·8	14·4	15·4	17·2	I	,,	11·4	14·6	12·6	15·4
94	III	,,	49·2	44·2	54·0	44·6	III	,,	21·7	25·8	29·0	20·8
95	II	,,	31·8	32·0	32·0	31·2	II	,,	19·4	28·7	22·7	27·0
96	IV	Peas	36·2	37·2	39·4	35·4	IV	Peas	26·0	32·6	29·0	27·8
97	I	Clover-hay	10·0	10·0	12·0	10·0	I	Clover-hay	7·1	5·8	8·7	7·4
98	III	,,	45·8	43·3	46·5	49·3	III	,,	33·3	32·4	29·0	28·5
1905		Mustard ploughed in										
06	IV	Mustard	65·0	77·8	64·3	54·2						
07	I	,,	90·8	64·8	106·8	95·9	I	Mustard	97·8	104·9	96·0	93·6
08	III	,,	120·0	107·0	112·1	90·6	III	,,	87·5	81·8	84·1	70·1
09	II	,,	74·6	39·9	35·9	32·5	II	,,	105·5	103·5	76·5	69·8
1910	IV	,,	76·1	89·2	83·1	89·1	IV	,,	69·4	84·1	89·5	70·6

TABLE 142 (*continued*).—ROTATION SEEDS.

Year.	Crop.	Series C. Plot 1. Corn.	Series C. Plot 2. Cake.	Year.	Crop.	Series D. Plot 1. Corn.	Series D. Plot 2. Cake.
1912	Trefolium hay	39·4	36·7	1914	Mustard fed on		
1916	Rape fed on			1919	clover-hay	40·1	39·4
1920	clover-hay	56·7	56·6	1923	,,	47·5	48·4
1924	,,	38·7	37·1	1927	,,	60·7	42·5
1928	,,	59·6	33·4	1931	Tares (as hay reckoned on a basis of 15 per cent moisture)	15·9	13·9

TABLE 143.—ROTATION WHEAT. HEAD AND TAIL CORN, LB. PER ACRE.

Year.	Block.	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
1878	I	2434	2577	3007	2370	—	—	—	—
79	III	2106	2158	2274	2262	—	—	—	—
1880	II	1153	1339	1116	1301	—	—	—	—
81	IV	3354	3440	3483	3204	—	—	—	—
82	I	2019	2026	2540	2700	—	—	—	—
83	III	2724	2747	2582	2718	—	—	—	—
84	II	3027	3133	2848	3148	—	—	—	—
85	IV	2824	3127	2590	2759	—	—	—	—
86	I	1226	898	1226	885	1480	1359	1496	1494
87	III	2350	2120	1890	1898	1960	2033	2167	2172
88	II	1242	1208	1158	1167	1493	1470	1328	1324
89	IV	1656	1856	1980	1884	1581	1818	1728	1656
1890	I	2624	2494	2558	2430	2380	2216	2534	2376
91	III	2304	2458	2762	2727	2616	2572	2770	2751
92	II	1681	1656	1667	1732	1452	1468	1486	1528
93	IV	2382	2032	2505	2500	1730	1923	1926	1972
94	I	2944	2802	2774	2846	2774	2782	2862	2638
95	III	1910	1676	1936	1928	1780	1552	1702	1773
96	II	2206	2048	2038	2038	1950	2034	1873	1729
97	IV	1574	1648	1490	1535	1283	1287	1112	1208
98	I	2398	2397	2350	2332	2312	2468	2219	2261
99	III	2716	2252	2475	2500	2512	2033	2313	2330
1905	III	2284	2336	2407	2505	—	—	—	—
06	II	2286	2249	1708	1728	—	—	—	—
07	IV	1807	1727	1775	1823	—	—	—	—
08	I	1006	1112	1056	1083	890	1068	1237	1165
09	III	1135	1297	1372	1526	591	864	1035	956
1910	II	872	972	854	770	820	989	915	839
11	IV					731	883	752	588

TABLE 143 (*continued*).—ROTATION WHEAT.

Year.	Series C.	
	Plot 1.	Plot 2.
1913	1684	1425
1917	1125	1071
1921	2683	2350
1925	1685	1778
1929	1181	1022
1933	1602	1828

Year.	Series D.	
	Plot 1.	Plot 2.
1915	1100	1241
1920	1670	1756
1924	1062	1108
1928	1167	1262
1932	1062	1191
—	—	—

TABLE 144.—ROTATION WHEAT. TOTAL PRODUCE, LB. PER ACRE.

Year.	Block.	Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
1878	I	7330	7192	9585	7946	—	—	—	—
79	III	8032	8306	9460	8841	—	—	—	—
1880	II	4987	5651	5558	5474	—	—	—	—
81	IV	8058	8167	8933	8498	—	—	—	—
82	I	8323	8244	8876	9200	—	—	—	—
83	III	7798	8057	8840	8746	—	—	—	—
84	II	9726	9709	8743	9261	—	—	—	—
85	IV	9362	9515	8492	8186	—	—	—	—
86	I	2794	2160	2689	2097	3306	3026	3249	3385
87	III	5506	4828	4727	4664	4559	4712	5277	5426
88	II	3173	3172	3124	3059	3931	3855	3484	3414
89	IV	4897	5347	5396	5424	4374	4850	4580	4303
1890	I	6396	5954	6276	6245	5812	5347	6032	5894
91	III	7202	7349	7748	7464	7204	7114	7879	7731
92	II	4748	4650	4329	4357	4691	4732	4382	4288
93	IV	5356	5903	5913	5949	3894	4260	4433	4400
94	I	7542	7336	7167	7313	6582	6489	7060	6368
95	III	4264	3685	4256	4140	3996	3334	3804	3848
96	II	5187	4676	4411	4389	4434	4474	4103	3778
97	IV	3855	3839	3519	3671	3035	2927	2540	2761
98	I	5760	5713	5404	5411	5385	5857	5123	5237
99	III	6500	5375	5845	5981	5469	4597	5330	5510
1905	III	5777	5811	6034	6451	—	—	—	—
06	II	5404	5351	4097	4172	—	—	—	—
07	IV	4828	4629	4703	4698	—	—	—	—
08	I	2406	2479	2400	2402	2116	2460	2884	2638
09	III	3165	3407	3462	3805	1767	2288	2754	2645
1910	II	2275	2329	2004	2019	2115	2521	2259	2175
11	IV	—	—	—	—	1810	2112	1853	1470

TABLE 144 (*continued*).—ROTATION WHEAT.

Year.	Series C.		Year.	Series D.	
	Plot 1.	Plot 2.		Plot 1.	Plot 2.
1913	3975	3652	1915	2610	3051
1917	3124	3185	1920	3896	4026
1921	6496	5938	1924	2540	2900
1925	4079	4424	1928	2869	3188
1929	2693	2366	1932	2888	3487
1933	4010	4516	—	—	—

TABLE 145.—STACKYARD FIELD: GREEN-MANURING EXPERIMENTS.
HEAD AND TAIL CORN, LB. PER ACRE.

Wheat, Harvest Year.	After Tares. 1.	After Rape. 2.	After Mustard. 3.
	991 [1]	1195 [1]	1189 [1]
1912	1117	1197	888
1914	995	1228	1089
1916	520	653	727
1918	716	887	887
1920	663	878	928
1922	419	—	446
1923	507	—	355
1924	422	—	532

[1] Lower end of field.

Year.	After Tares.		After Mustard.	
	Unlimed.	Limed.	Unlimed.	Limed.
1925	461	342	414	317
1926	303	334	220	160
1927	311	158	418	130
1928	458	485	497	246
1929	536	334	482	330
1930	104	—	309	—
1931	636	528	529	511
1932	364	521	541	339
1933	635	554	730	523
1934	478	565	695	526
1935	791	—	637	—

TOTAL PRODUCE, LB. PER ACRE.

Wheat, Harvest Year.	After Tares. 1.	After Rape. 2.	After Mustard. 3.
	2330 [1]	2804 [1]	2752 [1]
1912	2684	2850	2147
1914	2439	2958	2694
1916	1536	1745	1920
1918	—	2641	2660
1920	2013	2101	2110
1922	1290	—	1403
1923	1549	—	949
1924	1396	—	1596

[1] Lower half of field.

TABLE 145 (*continued*).

Year.	After Tares.		After Mustard.	
	Unlimed.	Limed.	Unlimed.	Limed.
1925	1389	1091	942	771
1926	1264	1308	955	619
1927	1588	1356	1448	903
1928	1477	1583	1583	862
1929	1466	1118	1311	946
1930	462	—	959	—
1931	1980	1547	1347	1329
1932	1462	2145	1784	1235
1933	2013	1988	2410	2259
1934	1598	1685	1893	1489
1935	1875	—	1436	—

TABLE 146.—LANSOME FIELD: GREEN-MANURING EXPERIMENTS. HEAD AND TAIL CORN, LB. PER ACRE.

Year.	Crop.	After Tares.		After Rape.		After Mustard.	
		No Mineral Manures.	Mineral Manures.	No Mineral Manures.	Mineral Manures.	No Mineral Manures.	Mineral Manures.
1893	Barley	2283	2241	2022	2380	1779	2230
1895	,,	1776	1504	1881	2076	2104	2374
1897	Wheat	1062	954	938	1412	1095	1312
1899	,,	1213	1736	1556	1495	1912	1882
1901	,,	661	598	961	988	1171	1195
1903	,,	1161	1140	1222	1486	1725	2403
1904	Barley	1044	1048	958	916	1077	1134
1906	Wheat	1640	1603	2276	2142	2195	2423
1908	,,	954	768	1422	962	1524	1382
1910	,,	1024	895	1613	1149	1491	1356
1912	,,	590	553	721	761	912	1026
1913	Oats	1120	1151	973	1053	1094	943
1915	Wheat	1085	1098	1213	1268	1033	1076
1917	,,	583	—	591	—	571	—

TABLE 146 (*continued*).

Year.	Crop.	Old Plots. After Tares.	Old Plots. After Mustard.	New Plots. After Tares.	New Plots. After Mustard.	New Plots. After Fallow.
1923	Wheat	450	443	461	460	364
1925	,,	282	434	287	295	254
1927	,,	—[1]	—[1]	24	8	20
1929	,,	2161	1583	1801	1346	1079
1931	,,	801	576	684	746	532
1933	,,	569	571	589	617	536
1935	,,	1045	659	742	707	607

TOTAL PRODUCE, LB. PER ACRE.

Year.	Crop.	After Tares. No Mineral Manures.	After Tares. Mineral Manures.	After Rape. No Mineral Manures.	After Rape. Mineral Manures.	After Mustard. No Mineral Manures.	After Mustard. Mineral Manures.
1893	Barley	4371	4584	4323	4696	3744	4672
1895	,,	3645	3388	3582	4032	4436	5036
1897	Wheat	3729	3072	3005	4298	3117	3336
1899	,,	3436	4856	4028	4192	4978	5138
1901	,,	2003	1660	2365	2605	2840	2979
1903	,,	3297	3210	3141	4198	4849	6555
1904	Barley	2149	2284	1999	1969	2442	2436
1906	Wheat	3642	3559	5292	5005	4947	5574
1908	,,	1960	1771	3016	2226	3154	3021
1910	,,	2617	2155	3875	2763	3625	3373
1912	,,	1476	1454	1718	1790	2074	2353
1913	Oats	2417	2390	2179	2401	2681	2270
1915	Wheat	2586	2598	3007	3101	2609	2786
1917	,,	1451	—	1323	—	1558	—

Year.	Crop.	Old Plots. After Tares.	Old Plots. After Mustard.	New Plots. After Tares.	New Plots. After Mustard.	New Plots. After Fallow.
1923	Wheat.	1839	1440	2018	1502	1327
1925	,,	1562	1906	1607	1783	1790
1927	,,	—[1]	—[1]	315	277	513
1929	,,	5499	4148	5116	3586	3756
1931	,,	2615	1707	3170	2381	1753
1933	,,	1935	1993	1877	1927	1589
1935	,,	3782	2219	2821	2577	2303

[1] Plots harvested green, no yields taken.

Note.—Tables 145 and 146 are taken from the published figures, as the primary data are not available for some years.

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